...udy of the Health Effects of ...cling in an Urban ...osphere

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16. Abstract This report analyzes data on the health effects of bicycling in an urban environment through intensive study of ten healthy male subjects bicycling or driving in systematically varied conditions in the streets of Washington, D.C. Evaluation criteria for available technology and instrumentation are included and a methodology is developed for route selection. Specific air pollutants (carbon monoxide, ozone, sulfates, nitrates, and particulates) are measured concurrently with exposure and subsequent changes in health status identified through pulmonary function testing, cardiovascular testing and blood and symptoms analysis. The report concludes that no major adverse short-term health effects were noted for ten healthy male subjects while bicycling or driving in levels of pollution and thermal stress encountered during the study period. Recommendations for further research are also presented.

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METRIC CONVERSION FACTORS

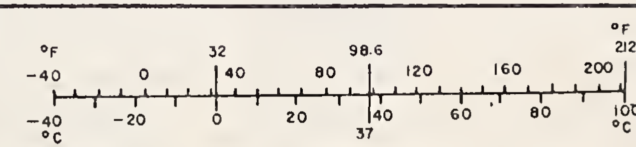
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286. Units of Weights and Measures. Price $2.25. SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABBREVIATIONS

AQI	Air Quality Index
B	Bicyclist(s)
$\overline{BH}$	Average building height
B.P.	Blood Pressure
BTPS	Body temperature and pressure, saturated with water vapor
BW	Block Width
CAMP	Continuous Air Monitoring Project
cfh	Cubic feet per hour
CO	Carbon monoxide
CO_C	*In situ* concentration of Carbon Monoxide
CO_S	Derived concentration of Carbon Monoxide from permanent air monitoring station
COG	Council of Governments
COH	Coefficient of Haze
COHb	Carboxyhemoglobin
ΔCOHb	Change in concentration of carboxyhemoglobin
D.F.	Degree(s) of Freedom
ECG, EKG	Electrocardiogram
EMI	Environmental Measurements, Inc.
EPA	Environmental Protection Agency
^oF	Degrees Fahrenheit
FEF_{50}	Forced Expiratory Flow at 50 percent of Forced Vital Capacity
FEF_{50B}	Baseline Forced Expiratory Flow at 50 percent of Forced Vital Capacity
FEV_1	Forced Expiratory Flow at 1 second

FEV_3	Forced Expiratory Flow at 3 seconds
$FEF_{25-75\%}$	Forced Expiratory Flow measured during the middle half of expiration
HR	Heart rate
HR_B	Baseline heart rate
IC	Integrated Circuit
L	Liter(s)
M	Motorist(s)
MAPHR	Maximum Age Predicted Heart Rate
m^3/hr	Cubic meters per hour
mm	Millimeters
mm/Hg	Millimeters of mercury
mph	Miles per hour
MSA	Mine Safety Appliances (Corporation)
NiCd	Nickel-Cadmium
NO	Nitrogen Monoxide (Nitric Oxide)
NO_2	Nitrogen Dioxide
O	Atomic Oxygen
O_2	Molecular Oxygen
O_3, OZ	Ozone
OH•	Hydroxyl (radical)
Oz.	Ounces
P.A.	Partitioning Attribute
PAN	Peroxyacyl nitrate
P.F.	Peak Flow
$PFEF_{25-75\%}$	Percent of Predicted Forced Expiratory Flow during the middle half of expiration
$PFEF_{25-75\%B}$	Baseline percent of Predicted Forced Expiratory Flow during the middle half of expiration
$PFEV_1$	Percent of Predicted Forced Expiratory Volume at 1 second

$PFEV_{1B}$	Baseline percent of Predicted Forced Expiratory Volume at 1 second
PFVC	Percent of Predicted Forced Vital Capacity
$PFVC_B$	Baseline percent of Predicted Forced Vital Capacity
PO_X	Photochemical Oxidants
ppb	Parts per billion
PPF	Percent of Predicted Peak Flow
PPF_B	Baseline percent of Predicted Peak Flow
ppm	Parts per million
RH	Relative Humidity
$RPFEF_{50}$	Relative change in percent of Predicted Forced Expiratory Flow at 50 percent of Forced Vital Capacity
$RPFEV_1$	Relative change in percent of Predicted Forced Expiratory Volume at 1 second
RPFVC	Relative change in percent of Predicted Forced Vital Capacity
RPPF	Relative change in percent of Predicted Peak Flow
RTET	Relative change in Total Elapsed Time (treadmill)
RW	Road width
S.D.	Standard Deviation
SO_2	Sulfur Dioxide
T	Temperature
T(g)	Real time of trip
TET	Total Elapsed Time (treadmill)
TSN	Total Soluble Nitrate
TSP's	Total Suspended Particulates
TSS	Total Soluble Sulfate
V	Volt

SYMBOLS

R^2	Coefficient of multiple determination
F	F statistic
F(.95)	Value of F statistic at 95 percent level of significance
t	t statistic
t(.95)	Value of t statistic at 95 percent level of significance
χ^2	Chi square statistic
$\chi^2(.95)$	Value of Chi square statistic at 95 percent level of significance
b	Slope (of a line)
r	Correlation coefficient (bivariate linear regression)
μm	Micrometer(s)
$\mu g/m^3$	Micrograms per cubic meter
%	Percent

SUMMARY

The Department of Transportation (DOT) has encouraged the use of bicycles since 1971 as an energy conservation measure, to improve traffic movement in congested urban centers, and to reduce air pollution. Policy to encourage bicycling, however, is being considered in a vacuum of research on the health effects of bicycling in an urban environment. This study has been designed to provide preliminary data on this issue by identifying and measuring the types and concentrations of pollutants that bicyclists and motorists are exposed to on a variety of routes, measuring the actual short-term changes in the health status of these subjects after exposure, and analyzing the relationships that exist between levels of pollutants, short-term changes in health status, types of exposure (bicycling vs. driving), lengths of exposure, and types of routes.

Ten healthy male subjects were selected utilizing a set of screening criteria and then re-tested to establish baseline values for cardiovascular and pulmonary function. They were then randomly assigned to bicycle or drive for 30 minutes and 60 minutes on routes that had been designed to reflect high and low volumes of traffic and high and low building density during the p.m. peak traffic hours on the streets of Washington, D.C. Specific air pollutants (carbon monoxide, ozone, total soluble sulfates, total soluble nitrates, and particulates) were measured concurrently during the test runs.

Changes in health status were identified through: examination for 11 signs and symptoms before and after each exposure; analysis of blood for carboxyhemoglobin levels before and after each exposure; a series of pulmonary function tests following exposure that examined the performance of the large and small airways in comparison to predicted norms and the subjects' established baseline values; and maximal multi-stage exercise testing which was used as an indirect measure of oxygen transport capacity following exposure and performance compared to established baseline values for each subject.

Chapter I discusses the purpose of the study, the broad research objectives and the scope of the study. Chapter II details the operational plan for the study and includes a discussion of the criteria established

and utilized for air pollutant selection, route selection, subject selection, and experimental methods. Chapter III describes the data analysis plan and discusses the findings and observations related to the testing of a series of research hypotheses. Chapter IV summarizes the study's findings and observations and presents the conclusion that no major adverse short-term health effects were noted in the ten healthy male subjects who participated in the study. Recommendations for further research are also presented.

I. INTRODUCTION

The Department of Transportation (DOT) has encouraged the use of bicycles since 1971 as an energy conservation measure, to improve traffic movement in congested urban centers, and to reduce air pollution. Other important advantages recognized by the DOT are that bicycles are inexpensive and thus more widely available to the commuting public, require little storage space, and reduce the urban noise environment.

The most recent guidance on transportation planning in urban areas by the DOT mandates the development of an urban transportation planning process coordinated with air quality planning conducted pursuant to 42 U.S.C. 1857 (Clean Air Act). The urban transportation planning process is required to include a transportation systems management element (short-range plan) as well as long-range plan. The guidance suggests that the transportation systems management element emphasizes, among others, actions to ensure the efficient use of existing road spaces and actions to reduce vehicle use in congested areas, mentioning improvements for bicyclists in both cases.

In order to consider the hazards/benefits of shifting to greater bicycle use for transportation energy conservation, improvement in traffic flow, and reduction in air pollution, it is necessary to address a number of unanswered questions. One of the most critical is that of the health effects of bicycling in an urban environment. This study has been designed to provide preliminary data on this issue by identifying

and measuring the types and concentrations of pollutants that bicyclists and motorists are exposed to on a variety of routes, measuring the actual short-term changes in the health status of these subjects after exposure, and analyzing the relationships that exist between levels of pollutants, short-term changes in health status, types of exposure (bicycling vs. driving), lengths of exposure and types of routes.

The results of this study can be used to:

- Develop guidance on transportation investment and policies keyed to environmental, energy, efficiency, and health goals.
- Develop predictions of health hazards/benefits of modal switch to bicycles.
- Develop tradeoffs between energy savings and health effects of a modal switch to bicycling.
- Inform the public of hazards/benefits of urban bicycling.
- Evaluate existing Federal policies encouraging bicycling.

1. PURPOSE OF THE STUDY

This study is not designed to provide definitive answers to the myriad of research and policy questions concerning bicycling in an urban environment. Rather, it is intended as a preliminary study to provide data through:

- Intensive study of a small sample of bicyclists and motorist controls under systematically varied conditions in an urban environment.

- Investigation of the actual adverse short-term health effects experienced by these subjects.

- Evaluation of the adequacy of available technology and instrumentation for such investigations.

- Analysis of the resources, technological sophistication and personnel necessary to conduct studies of this type.

2. BROAD RESEARCH OBJECTIVES FOR THE STUDY

The following broad research objectives for the study were identified:

- To measure some of the actual levels of pollutants that motorists and bicyclists are exposed to during a normal commuting trip under a variety of conditions.

- To develop a better understanding of interrelationships that exist between environmental factors, short-term changes in health status, types of exposure (bicycling vs. driving), lengths of exposure, and types of routes.

- To identify some of the health factors that are most affected by the combination of exercise and exposure to pollutants encountered in an urban environment.

- To compare the results of monitoring of some pollutants at actual exposure levels with the levels from air monitoring stations.

- To develop procedures and select technology for carrying out this type of research.

- To make recommendations for further research based on the results of this preliminary study.

These objectives were further expanded into a series of experimental hypotheses to be tested, which are described in Chapter III, Section 1.

3. SPECIAL NOMENCLATURE USED IN THE STUDY

The following special nomenclature is used to describe the design of this study and to portray results:

- Experimental Design Case (or Case for short), which refers to a single bicyclist or motorist moving from the beginning to the end of a predetermined path under a predetermined set of conditions.

- Experimental Design Partitioning Category, which refers to a single category of predetermined conditions that describe an Experimental Design Case (e.g., planned length of trip).

- Experimental Design Partitioning Attribute, which refers to one of a number of possible predetermined conditions under a single experimental design partitioning category (e.g., under the partitioning category "planned length of trip," the partitioning attributes would be 60 minutes and 30 minutes).

- Experimental Design Cell (or Cell for short), which is constructed by the intersection of one attribute from each partitioning category (i.e., if there are "C" partitioning categories, a single cell will be defined by "C" attributes. Also, the number of cells will be given by the product of the number of attributes in each partitioning category).

- Health Status Evaluation Category, which refers to a single category of health status evaluation (e.g., symptoms).

- Health Evaluation Attribute, which refers to one of a number of possible dimensions under a single health status evaluation category (e.g., under the category of "signs and symptoms," three health evaluation attributes would include coughing, fatigue, and headache).

- Health Evaluation Variable, which is a measurable characteristic or measurable mathematical construct of of a health evaluation attribute (e.g., a discrete variable for the symptom of headache could be constructed as taking on the numerical value 1.0 if a headache occurs and 0 if it does not; a continuous variable for the symptom

of headache could be constructed as taking on any real value between zero and 1.0 with more severe headaches given the higher number; a directly measured variable could be the actual blood pressure measured for a bicyclist at a point in time after completing the trip).

- Pollutant Category, which refers to a subjective grouping of pollutants (e.g., air, water, noise).

- Pollutant, which refers to one of a number of possibly harmful substances under a single pollutant category (e.g., under "air pollution," a number of pollutants are carbon monoxide, total particulates, and ozone).

- Pollutant Variable, which is a measurable characteristic or measurable mathematical construct of a pollutant (e.g., the average concentration of carbon monoxide measured in parts per million over an hour).

4. SCOPE OF THE STUDY

The scope of the study was dependent in part on the study's budget, which placed certain limitations on design factors that could be used, such as currently available equipment and health status testing protocols, the number of experimental design cases, and the size and nature of suitable testing and control groups. As a result, various design options were postulated and their respective costs estimated. Only those options within budget were acceptable.

Remaining options were assessed on the basis of a number of heterogeneous factors, including equipment accuracy and maintenance, bicycle weight load, and a desire to minimize the influence of exogenous conditions (e.g., exposure just prior to or just after the experiment). As a result, the study consists of the following design characteristics:

- Three (3) experimental design partitioning categories were defined—mode of transportation, planned length of trip, and traffic environment.

- Mode of transportation was assigned two (2) experimental design partitioning attributes—bicycle and automobile (the control group).

- Planned length of trip was assigned two (2) experimental design partitioning attributes—30 minutes and 60 minutes.

- Traffic environment was assigned four (4) experimental design partitioning attributes— little or no traffic, few or no buildings; high traffic, few or no buildings; high traffic, high building density; and little or no traffic, high building density.

- Sixteen (16) experimental design cells were formed by the eight attributes, as shown in Exhibit 1 on the next page, along with the number of cases to be run for each cell.

- Four (4) health status evaluation categories were defined— blood tests, exercise tests, pulmonary screening tests, and symptoms checks.

- The category of blood tests was assigned one (1) health evaluation attribute— venous carboxyhemoglobin level.

- The category of exercise tests was assigned four (4) health evaluation attributes—blood pressure, heart rate, EKG reading, and total exercise time.

- The category of pulmonary screening tests was assigned 11 health evaluation attributes—forced vital capacity (FVC), percent of predicted FVC, one-second forced expiratory volume (FEV_1), percent of predicted FEV_1, ratio of FEV_1 to FVC expressed as a percentage, ratio of three-second forced expiratory volume (FEV_3) to FVC expressed as a percentage, peak expiratory flow (PF), percent of predicted PF, forced expiratory flow at 50 percent of FVC, $FEF_{25-75\%}$, and percent of predicted $FEF_{25-75\%}$.

EXHIBIT 1

Identification of Experimental Design Cells [a]

Mode of Transportation Partitioning Attributes	Planned Length of Trip Partitioning Attributes	Traffic Environment Partitioning Attributes			
		Traffic, high building density Route W	Traffic, little or no buildings Route X	Little or no traffic, little or no buildings Route Y	Little or no traffic, high building density Route Z
Bicycle	30 minutes	7	6	7	6
	60 minutes	7	7	7	7
Automobile (Control Group)	30 minutes	3	3	3	3
	60 minutes	3	3	3	3

(a) Number in each cell is the number of cases run in that cell.

- The category of signs and symptoms was assigned 11 health evaluation attributes—cough, wheeze, sputum production, substernal pain, dyspnea, fatigue, headache, sore throat, laryngeal irritation, nasal discharge, and eye irritation.

- Five (5) air pollutants were included—carbon monoxide, total soluble sulfates, total soluble nitrates, ozone, and particulates.

- Seventy-eight (78) experimental design cases were run, fifty-four (54) bicycle and twenty-four (24) automobile.

A summary of health evaluation and pollutant categories and attributes is presented as Exhibit 2 on page 9.

EXHIBIT 2

Summary of Health Status and Pollutant Categories and Attributes

<table>
<tr><th>Health Status Evaluation Category</th><th>Health Evaluation Attribute</th><th>Pollutant Category</th><th>Pollutant</th></tr>
<tr><td>Blood Tests</td><td>Venous Carboxyhemoglobin Level</td><td rowspan="8">Air Pollution</td><td rowspan="2">Carbon Monoxide</td></tr>
<tr><td rowspan="2">Exercise Tests</td><td rowspan="2">Blood Pressure
Heart Rate
EKG Reading
Total Exercise Time</td></tr>
<tr><td rowspan="2">Total Soluble Sulfates</td></tr>
<tr><td rowspan="3">Pulmonary Screening Tests</td><td rowspan="3">FVC
% of Predicted FVC
FEV_1
% of Predicted FEV_1
FEV_1/FVC as %
FEV_3/FVC as %
PF
% of Predicted PF
Forced Exp. Flow at 50% of FVC (FEF_{50})
$FEF_{25-75\%}$
% of Predicted $FEF_{25-75\%}$</td></tr>
<tr><td>Total Soluble Nitrates</td></tr>
<tr><td rowspan="2">Particulates</td></tr>
<tr><td rowspan="2">Signs and Symptoms</td><td rowspan="2">Cough
Wheeze
Sputum Production
Substernal Pain
Dyspnea
Fatigue
Headache
Sore Throat
Laryngeal Irritation
Nasal Discharge
Eye Irritation</td></tr>
<tr><td>Ozone</td></tr>
</table>

II. THE OPERATIONAL PLAN FOR THE STUDY

1. AIR POLLUTANT SELECTION AND TESTING

1.1 Pollution Climatology in the Washington Metropolitan Area

Washington's pollution climatology is affected primarily by its vehicular exhaust emissions and weather patterns. Because very little industry is located in the Washington area, the pollution results almost entirely from vehicular exhaust.

Washington's annual weather patterns are characterized by frequent temperature inversions during winter mornings, causing CO build-ups, and frequent stationary high pressure dome patterns in the summer, often for several days in sequence. The predominant factor is the massive Bermuda high pressure zone, which is characterized by slow winds and sunny skies, and is very favorable for photochemical smog formation. The Bermuda high has been known to persist over the city for periods upward to two weeks or more during the summer, and is the major system responsible for local air stagnation episodes.

Typical pollutant concentrations have been described as follows:

- CO levels at major intersections routinely tend to exceed one-hour and eight-hour primary standards, levels ranging from 1.0-10.6 ppm over eight hours for the past several years[1]. The citywide levels,

however, only tend to exceed the primary standard during a.m. winter periods, for the reasons previously specified. The one-hour primary standard for CO (35 ppm) in particular has been frequently violated between December and March, with a measurement of 80 ppm once recorded.

- Ozone concentrations persistently exceed the secondary air quality standard (40 ppb) for photochemical oxidant in the summer months. Averages of 50 ppb (24-hour) are common with episode levels in excess of 135 ppb having been recorded, well over the primary standard (80 ppb).[1] This is the major pollution danger to Washington. For example, at the CAMP[(a)] station, the primary standard for ozone was exceeded 31 times in 1975, resulting in three alerts. Levels drop off sharply during the short solar days and increased winds of the autumn-winter months, varying between zero and 40 ppb.

- Suspended particulates (including sulfates and nitrates) widely fluctuate in concentration from day to day, and tend to be very localized. Construction activity is the major source of these pollutants (although automobiles are also a source). Twenty-four-hour levels ranged from 14 to 203 $\mu g/m^3$ during the 1975 summer months, averaging to 53 $\mu g/m^3$ (annual mean) below even the national secondary air quality standard for this pollutant (63 $\mu g/m^3$).[1]

- Metropolitan sulfate levels have only recently been observed (since 1975). Summertime levels range from 3 to 30 $\mu g/m^3$. There are no standards set for these compounds to date for the D.C. area, other than those derived from the total suspended particulates standards.

(a) Continuous Air Monitoring Project (CAMP): laboratories under the auspices of the U.S. Environmental Protection Agency for the purpose of detailed, continuous analysis of local air masses for pollutant content.

- Sulfur and nitrogen oxides by themselves have not posed a threat to the general health of the Washington area in recent years. Both annual arithmetic means are well below primary standards, and no violations of daily or hourly standards have been apparent.

In the District of Columbia, the measurement of these pollutants is done by the use of a scale ranging from zero to over 750, called the Air Quality Index (AQI). This scale is based upon each pollutant's impact upon health and welfare as defined by nationwide air quality standards.

The index is divided into labelled intervals corresponding to measured health or environmental potential for damage; see Table 1 on the following page for a description of each interval.

An alert is broadcast if AQI levels exceed 99 for more than 24 hours. A warning is issued at AQI levels over 249, and 750 represents the emergency stage. When AQI exceeds 99, the air is usually called "very unhealthy."

The value of AQI is a "worst-case" figure. It is calculated by taking the measured concentration of each pollutant from each measuring station, looking up its corresponding AQI number from a series of graphs for each pollutant, and then choosing the pollutant with the highest number. Thus, if only one station was to have measured a concentration for only one of its measured pollutants that corresponded to an AQI value of (example) 105, that value would be broadcast as the area's AQI.

As a further example of the calculation of this number, the concentration of each of the five pollutants that would correspond to AQI = 100 is specified in Table 2 on the following page.

TABLE 1

Divisions of the Air Quality Index

Index Number Interval	Effect
0-24	None
25-49	Damage to Plants and Materials
50-74	Long-Term Damage to Human Health
75-99	Increasing Long-Term Damage to Human Health
100-249	Short-Term Effects to Health of Sensitive Persons
250-749	Short-Term Effects to the Health of the General Public
750+	Severe Damage to Human Health

TABLE 2

Concentration Values Corresponding to AQI of 100

Pollutant	Concentration
Sulfur Dioxide (SO_2)	0.70 ppm
Nitrogen Dioxide (NO_2)	0.60 ppm
Particulate Matter	5.50 COH
Carbon Monoxide (CO)	60.0 ppm
Photochemical Oxidants (PO_x)[a]	0.10 ppm

(a) Including ozone

Frequently, the AQI values recorded during the runs were much less than the highest values of the day. This is because of the peculiar nature of photochemical smog, which is formed by a set of chemical reactions driven by sunlight. The general reactions for oxidant production are:

1. NO (from auto exhaust) + $O_2 \rightarrow NO_2 + O$
2. $O_2 + NO_2$ + sunlight $\rightarrow NO + O_3$ (Ozone)
3. $O_3 + NO \rightarrow NO_2 + O_2$

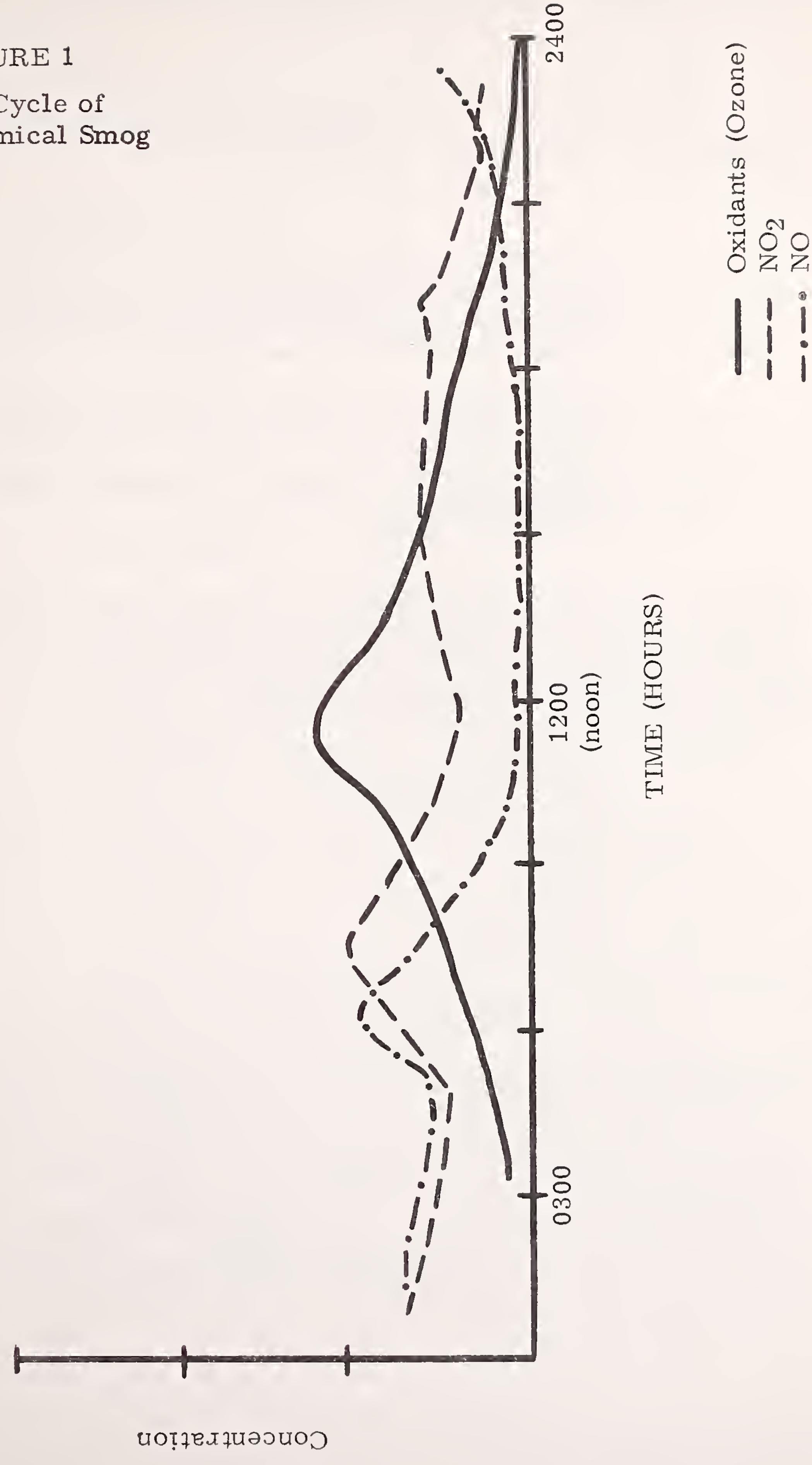
Note the cyclical nature. The stronger the sunlight, the more ozone is produced; the weaker the sunlight and the greater the concentration of NO gas, the more ozone is consumed. Thus, ozone concentration is generally highest between noon and 3 p.m. (in the summertime) when sunlight is strongest and auto traffic has slackened.

During the afternoon rush hours, however, (when sampling occurred) sunlight is ebbing and the increased volume of combustion-created vehicular exhaust produces an increase in NO concentration, which "eats up" ozone and produces NO_2. The standard for NO_2 is six times that for ozone (oxidants); therefore, to equal the health effects of a given quantity of ozone, six times that quantity of NO_2 must be produced. And, since the sampling zone is in the midst of the greatest density of traffic, the conversion occurs more rapidly than in the suburban areas.

Thus, in summary, a different species of pollutant dominates during the afternoon rush-hour, producing a different AQI value from those of preceding hours. See Figure 1 on the following page for an illustration of the diurnal photochemical smog cycle.

FIGURE 1

Daily Cycle of
Photochemical Smog



1.2 Types of Pollutants Considered for Monitoring

Our choice of the pollutants that were examined with regard to making in situ air quality measurements during this study was based upon the following considerations:

- A determination of the pollutants (to which bicyclists would likely be exposed in the traffic stream) that would have levels high enough to possibly cause health effects (see Appendix N).
- A determination of which of the health effects had indicators that were measurable (both baseline measurements and changes in baseline) given the scope of study.

Based upon these considerations, we recommended that the exposure levels of the following pollutants be monitored (both on the bicycle and in the automobile) during this study:

- Carbon Monoxide (CO)
- Sulfates
- Nitrates
- Particulates[a].

Because ozone occurs as a chemical by-product following the emission of primary pollutants, it is widely dispersed and can be validly measured at permanent air monitoring stations with less variability in concentration. For this reason and

(a) Particulates were measured, but because all results were below detectable levels, this study was unable to analyze the relationship of particulates to health effects.

because stable, reliable, and portable ozone measuring devices are not presently available, in situ exposure levels of ozone were not determined.

1.3 Pollution Monitoring Techniques

(1) Evaluation Criteria

Information concerning suitable techniques for monitoring each of the above four pollutants on a bicycle and in an automobile was obtained from the following sources:

- Literature review of previous studies on the health impacts of exposure to each of these pollutants.
- Review of techniques and instrumentation discussed in Instrumentation for Environmental Monitoring, Volume 1, Parts 1 and 1A, AIR-GASES, and Volume 1, Part 2, AIR-PARTICULATES, Lawrence Berkeley Laboratory, University of California, Berkeley, California, revised September 1976.
- Review of descriptive and technical material supplied by over 20 manufacturers of monitoring equipment.
- Review of relevant articles in the Journal of the Air Pollution Control Association.
- Discussions with personnel of the D.C. Department of Environmental Services, the Maryland Bureau of Air Quality Control, Montgomery County (Md.) Department of Environmental Protection, and the Fairfax County (Va.) Department of Environmental Management.
- Relevant staff experience.

The following evaluation criteria were then used to select instrumentation and/or techniques that were suitable for monitoring the four pollutants listed above:

- "State-of-the-art": Any type of instrument or chemical analysis technique proposed for use has been used in previous studies, has been accepted as valid in the scientific community, and has the ability to measure pollutant levels in the ranges expected to be encountered during this study.

- Reliability: Any pollutant level measured or derived using a specific instrument or technique is expected to be within two percent of the actual pollutant level.

- Degree of compactness: Any monitoring device proposed for use readily fits on a bicycle; i.e., does not exceed 18 inches in any dimension.

- Suitability for mobile use: Any monitoring device proposed for use is battery powered.

- Weight: The weight of any proposed monitoring device (including strip chart recorder and batteries) does not exceed 12 pounds.

- Ease of operation: Any proposed monitoring device requires no action on the part of the bicyclist (or motorist) in order for data to be collected when the device is functioning properly.

- Safety: Any monitoring device proposed contains no toxic chemicals that could injure the bicyclist (or motorist).

- Cost: The total rental and/or fabrication cost and/or operating cost (exclusive of labor) of any proposed monitoring device does not exceed $1,500 for the proposed three-month monitoring period.

(2) Description of Equipment for In Situ Monitoring

CO Sampling

CO sampling equipment consisted of two Environmental Measurements, Inc. (EMI) "Pulse Pumps" which are interval-type pumps, approximately 6 oz. in weight, driven by a standard 1.5-V alkaline battery and timed by a 555-IC timer with variable potentiometer and 9-V alkaline battery. A fresh battery set is specified to pump 75-80 liters of air. Each pump interfaced to a Tedlar (polyvinyl fluoride) "grab-bag" with Roberts-type screw fitting for the valve. Tygon tubing interfaced the orifices of the bag and pump ports.

The EMI pumps are capable of delivering as much as 20 L of gas per hour, which is about .79 cfh or 0.023 m^3/hr. They were mounted forward on each bike (with the Tedlar bag resting in a basket) as close to the cyclist's head as possible. The pumps were set at flow rates which filled the Tedlar bag to 1.5 liters volume for each run. The "grab-bag" samples were closed upon return of the subjects, and stored in a container until they were analyzed. The pump maintenance schedule involved a daily check of the pump and batteries.

Particulates Sampling

Particulate, sulfate, and nitrate sampling was accomplished using Mine Safety Appliances (MSA) "Monitaire S" continuous pumping kits—four total, two per subject. Each kit consisted of a 12 oz. pump with range from 1-10 cfh (10 cfh = .28 m^3/hr.), a tubing interface, a plastic filter

holder with stainless steel support screen, and a 37 mm diameter, .45 μm pore size cellulose acetate filter. NiCd (nickel-cadmium) batteries power the pump motors (diaphragm), and are capable of eight-hour continuous duty. Recharge units can resuscitate a battery completely overnight.

The filters were chosen with regard to urban aerosol composition. Average particle size of an ambient aerosol varies, but the size range for most stable city-type aerosols is between 0.1 and 10 μm (diameter). Below 0.5 μm, however, particles become so small that their effective concentrations are generally negligible. Also, very finely-pored filters necessitate slow sampling rates which may result in insufficient particulates depositions for the purpose of analysis. The 37 mm holder size was chosen because that is the designated size for collar or shirt-top clip-on arrangements. The cellulose acetate filter medium was used because it is relatively sulfate/nitrate free compared to other commonly used media.[2]

Each filter was inserted into its appropriate holder on the day of sampling. Prior to this, one-half of the total filter set, plus ten "contingency" extras—making that a total of 90 filters—had been accurately weighed on an analytical balance and then placed in coded heat-sealable sterilized bags. Pumps were set between 8.5 and 10.0 cfh (cubic feet per hour).

The experienced air loadings were never sufficiently great to require corrections for clogging, i.e., flow rates, as measured off the rotameters, were constant in all cases.

The post-run filters were temporarily stored in their cassettes in sterile, plastic autoclavable bags (Fisher #1-815A). Later on, they were folded in half (to eliminate the possibility of abrasion loss) and inserted into heat-sealed plastic bags (Fisher #1-812-16) using stainless steel forceps washed in acetone.

The pump maintenance schedule involved daily checking of the pumps, and recharge of batteries.

(3) Description of Citywide (Ambient) Pollution Collection

The citywide or ambient pollution concentrations corresponding to each subject's time of ride were measured by a Council of Governments' (COG) operated Station, the West-End Library Station, located near Washington Circle. This station was situated very close to Route W as well as the common exit route for the bicyclists and motorists. Station to centroid distance was approximately one mile for Routes Y and Z, and one-half mile for Route X. (See Section 2.5 and Appendix I for description of routes.)

The sampling probe intake for the station is approximately 30 feet above the ground. Ozone, CO, and total suspended particulates (TSP's) are measured and recorded hourly.

Ozone is measured by the ethylene chemiluminescence reaction, CO is measured by the non-dispersive infrared absorption technique, and TSP's are evaluated using a high volume sampler and a mass difference (using an electronic

balance) procedure. All of the above techniques are approved by the U.S. Environmental Protection Agency (EPA), and all values are considered when citywide AQI's are calculated.

2. ROUTE SELECTION

2.1 Preliminary Criteria

A very important consideration in implementing this initial study of the health effects of bicycling in a urban atmosphere was the selection of routes that would validly and reliably reflect the study design and meet the objectives of the project.

Preliminary factors that affected route selection were:

- Safety of subjects and complexity of routes.
- Availability of traffic volume data
- Location of air monitoring stations for useful sampling sweeps
- Uniformity of routes in maintaining partitioning attribute criteria (traffic volume and building density) over 30 or 60 minutes for bicyclists and motorists
- Uniformity of route gradients
- Proximity of routes to George Washington University Medical Center.

Using these preliminary criteria, a methodology was developed and used to define traffic environment and to select routes that would reflect the following differences:

- High traffic volume/high building density (designated as Route W).

- High traffic volume/low building density (designated as Route X).

- Low traffic volume/low building density (designated as Route Y).

- Low traffic volume/high building density (designated as Route Z).

2.2 Traffic Volume

One of the important criteria for this study is the volume of traffic on each of the selected routes during testing times. Traffic volume relates directly to the volume of air pollutant emissions along that route and can be correlated with high air pollution areas.

Traffic volumes along a particular urban thoroughfare are determined by the number of motorized vehicles which pass along that route in both directions during a specified period of time. The D.C. Department of Transportation maintains total vehicle counts for the Washington Metropolitan Area measured at traffic counting stations for certain times of the day.

For this study, only the evening rush period of 4:00 to 6:00 p.m. was chosen as the test period. Data for total vehicle volume rush hour counts indicated that traffic volume was relatively uniform during the entire rush period.

Traffic volumes from these p.m. peak hour counts were obtained for various locations throughout the area and were analyzed to determine the break-off point for differentiating between low and high traffic volume routes. A methodology,

which is reproducible in a number of different environments, was developed for this purpose (see Appendix G), which resulted in the following definitions:

- Low volume 0 -1,500 vehicles/hour
- Medium volume 1,501 - 3,000 vehicles/hour
- Heavy volume 3,001 - 4,500 vehicles/hour
- Very heavy volume 4,501 - 6,000 vehicles/hour.

A route volume analysis was then made of a number of different route combinations and the route weight, or fractional distance of a particular route segment compared to the entire route, was determined. An <u>average weighted volume</u> was then computed (see Appendix G) with the following results:

Route	Average Weighted Volume
• Route W	3,128
• Route X	4,532
• Route Y	1,056
• Route Z	1,340.

2.3 Building Density

Certain zones in the city have the capacity to "bottle" pollutants for long durations depending on traffic volume, building heights, road and block widths, and the presence or absence of open spaces.

To develop a data base for ascertaining building densities along the routes, the following guidelines were used:

- Average Building Height, $(\overline{BH})$

  This parameter was derived by counting the numbers of attached buildings per section of city (usually, less than one block) and taking the average of all the story heights versus the quantity of buildings per section. For example, if a section of a block had six attached or closely spaced buildings, three of which were four stories tall and three of which were eight stories tall, then $\overline{BH}$ was six buildings, six stories high.

- Minimum Building Height

  To qualify as a structure which could effectively entrap air pollutants, a building had to be at least two stories high.

- Road Width (RW) and Block Width (BW)

  These were measured to assign values to areas characterized by spaces or other openings on at least one side of a line source. If BW was found to be much greater than RW, i. e., 15 times greater, then the area was one characterized by good ventilation, and thus low building density.

Using the above, we arrived at the following cutoffs:

- Low building density areas are comprised of either areas containing small buildings (less than two stories) adjoining the routes, or wide blocks surrounding small streets (BW at least 15 times greater than RW).

- High building density areas are comprised of areas consisting of narrow block widths relative to the intervening road widths and tall adjoining structures (greater than two stories tall).

Next, densities were summed, high or low per route, and then each route was designated as high or low density depending upon which characteristic was more prevalent.

The results produced the following conclusions:

- Route W consists of 94 percent high density sections and was therefore designated as a high density route.
- Route X is completely unbounded on at least one side the whole way, thus qualifying as a low density route.
- Route Y is also completely unbounded on at least one side throughout since BW/RW is greater than 15 in most cases and is therefore another low density route.
- Route Z consists of 84 percent high density sections and is therefore a high density route.

Exhibit 3 on the following page illustrates the three characteristics of a city block and the calculation of building densities for that block.

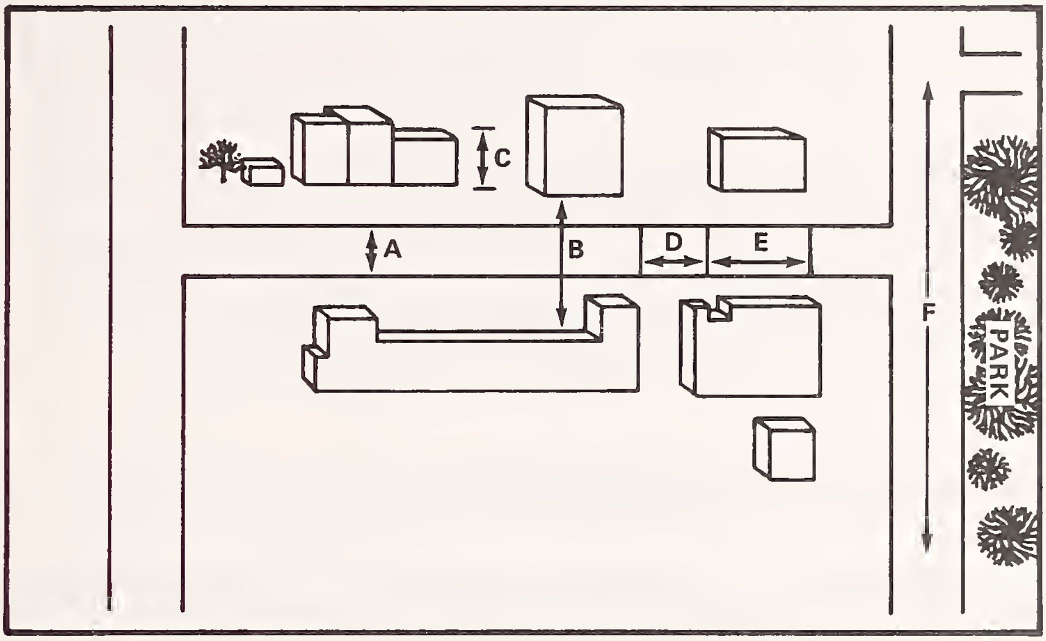
2.4 Bicycle Route Grade Equivalence

Because of the additional work which a bicyclist must perform in riding up a grade, it was important that all routes be as similar as possible in terms of relative frequencies of a particular grade. A methodology, based upon a study conducted for the Federal Highway Administration[26], was devised to define grade stratification (see Appendix H).

Measurements of gradients along a chosen route were obtained using a photogrammetric map indicating elevations above sea level. These measurements were made whenever the grade appeared to change a significant amount along a path tangent to the route.

EXHIBIT 3

Breakdown of a City Block
Into Density Parameters



In analyzing the block shown in Exhibit 3, define "A" to be road width, RW, "B" to be block width, BW, and "C" to be average building height, i.e., the average story height of a series of attached buildings with a similar set of buildings oppositely sited to it.

"D" represents a space in the block, i.e., a non-stagnant or low density zone. "E" represents a completely covered zone as defined under the constraints previously described, and thus is measured as a high density zone. "F" has no buildings at all on one side of its line source and is therefore a low density zone. "E" also has a BW/RW of less than 15 by scale measurement and therefore completely meets our requirements for a high density zone.

All routes were equivalent in distribution of grades, fairly easy to ride with only short, moderate hills, and included a common return route to maintain fairly equivalent grades.

The data for each route gradient analysis is presented in detail in Appendix H. It is important to note that the bicyclists rode downhill over roughly 50 percent of the total route distance and either on level ground or uphill the remaining 50 percent. They also encountered slight grades between 5 and 9 percent of the total route distance and moderate grades over approximately one percent. For a 30-minute route, the number of laps around the main route was simply reduced by half.

2.5 Description of Selected Routes

Four routes were chosen according to the previously described criteria relating to safety traffic volume, road gradients, building densities, ease of use, and proximity to the George Washington University Medical Center. As previously discussed, each cyclist or motorist traversed each route repetitively, in 30-minute and/or 60-minute intervals per test. These four routes were designated as Routes W, X, Y, and Z and are described in detail with accompanying maps in Appendix I. They are discussed briefly below.

- Route W was designated as the high volume/high density course. It is characterized by a very heavy volume of traffic and closely spaced highrise buildings, and consists of sections of K Street, Vermont Avenue, Massachusetts Avenue, and New Hampshire Avenue.

- Route X was designated as the high volume/low density circuit. It borders primarily on the Lincoln Memorial, Reflecting Pool, and Washington Monument grounds, areas which are heavily used during rush hours and lightly surrounded by obstructions.

- Route Y was designated as the low volume/low density circuit. It borders the Mall on Madison and Jefferson Streets, and is characterized by a relatively low volume of slow-moving traffic and open spaces.

- Route Z was designated as a low volume/high density circuit. It is located in a quiet residential section, north of Dupont Circle. The course was a circular zig-zag around the area which is mainly comprised of apartment buildings and townhouses spaced closely within each block.

Major problems encountered in the selection of routes included:

- Identifying routes that could maintain uniformity for the defined partitioning attribute (traffic volume/building density) over the entire circuit.

- The need for conclusion of the routes at the Medical Center required subjects to enter a high traffic volume/high building density area, if only for a short period of time.

- The difficulty in finding any low volume traffic routes in the city of Washington during the peak traffic hours.

3. SUBJECT SELECTION AND TESTING

3.1 Selection of Subjects

Active, experienced, non-smoking male and female bicycle commuters, 45 years of age or less, were recruited and interviewed to assess their interest and motivation for participating

in the study. Each candidate was asked to complete a health questionnaire. A positive response to questions regarding a history or current condition of asthma, allergic rhinitis, hay fever, sinusitis, or any cardiovascular problems eliminated the potential subject. Candidates who expressed excessive concern over re-arranging work schedules, had complex transportation requirements, or who expressed anxiety about the health questionnaire, blood tests, pulmonary function testing or cardiovascular tests were also eliminated.

If the subject met these preliminary criteria, and appeared to be well motivated and interested, he was asked to read and sign the form "Informed Consent for a Study on the Health Effects of Bicycling in an Urban Atmosphere" (see Exhibit 4 on the following page). Any individual refusing to sign the consent form was eliminated from further consideration.

Each potential subject was then given an initial screening examination by Patrick Gorman, M.D., Director of the Exercise Laboratory, George Washington University Medical Center and staff, consisting of a complete physical examination and a maximal multi-stage treadmill exercise test. Blood samples were drawn for complete blood count, hemoglobin, hematocrit, and carboxy-hemoglobin levels. A pulmonary function test on the "Predictive Pulmonary Screener" was administered by a trained technician under the supervision of Jerome Putnam, M.D., Director of the Pulmonary Function Laboratory, George Washington University Medical Center.

Potential subjects were required to meet the following criteria during the screening examination:

INFORMED CONSENT FOR A STUDY ON THE HEALTH EFFECTS OF BICYCLING IN AN URBAN ATMOSPHERE

I, ______________________________, desire to engage voluntarily in The Study on the Health Effects of Bicycling in a Polluted Atmosphere in the Metropolitan Area of the District of Columbia.

The purpose of this study is to provide further data on the actual exposure of bicyclists and non-bicyclists to a variety of pollutants under certain conditions. The study will include the riding of a bicycle on a prescribed route at a pre-arranged time terminating at George Washington University Medical Center in the District of Columbia or driving an automobile on a similar prescribed route at a pre-arranged time.

I understand that before I enter into this study I will be asked to complete a medical history form and will have a clinical evaluation by a physician at the George Washington University Medical Center. This evaluation will include further medical history, physical examination, a maximal multi-stage treadmill exercise test (which includes electrocardiograph recordings at rest and exercise, measurements of heart rate and blood pressure), a pulmonary function test and a blood sample drawn for laboratory analysis. I further understand that I shall return to the George Washington University Medical Center for a repeat of the maximal multi-stage treadmill exercise test, the pulmonary function testing, and the blood test. The purpose of these evaluations is to detect any condition which would indicate that I should not engage in this study.

Since I am presently riding a bicycle or driving in the Washington Metropolitan Area, there will be no additional risk involved in the bicycling or driving portion of the study than associated with my present bicycling or driving activities, other than following the prescribed route at a pre-arranged time.

At the beginning of the bicycling and driving activities, I will be asked questions about my health and a blood sample will be taken. At the conclusion of the bicycling and driving activities, I will participate in a maximal multi-stage treadmill exercise test, a pulmonary function test and a blood sample will be taken.

The Human Performance Laboratory at the George Washington University Medical Center is equipped and staffed to perform maximal multi-stage treadmill exercise. The principles of this test have been explained to me. I understand that I will be given a cardiovascular examination by a physician trained in physical exercise testing who will directly supervise the testing.

I understand that the Pulmonary Function Laboratory at George Washington University Medical Center is staffed by a trained technician and that pulmonary function testing will be performed.

I am aware that the reaction of the cardiovascular system to such activities cannot be predicted with complete accuracy. I understand that there is a minimal risk of adverse reactions occurring during or following the exercise testing. Before starting the study, I will be instructed as to signs and symptoms which I shall report promptly to the supervisor of the exercises who will be alert to changes which suggest that I should stop the exercise program. Every effort will be made to avoid any untoward events by the preliminary medical examination and observations during the exercise. Emergency equipment and trained personnel are available to deal with and minimize the dangers of untoward events should they occur.

I have read the foregoing and I understand it. Any questions which may have arisen or occured to me have been answered to my satisfaction.

SUBJECT ______________________________

ADDRESS ______________________________

____

DATE ______________________________

- No history of respiratory or cardiovascular disease
- Normal physical examination
- Blood pressure during supine rest less than 140/90
- Normal hemoglobin and hematocrit
- Normal resting 12 lead ECG
- Normal maximal multi-stage treadmill exercise test
- Normal pulmonary function test.

Potential subjects meeting these criteria during the initial screening examination were given another appointment between 4-6 p.m. for a repeat of the maximal multi-stage treadmill exercise test, the pulmonary function test and a blood sample for carboxyhemoglobin level. The second testing period was designed to establish "definitive baseline values," after giving the potential subject adequate training time with the equipment and answering any further questions.

Following the second testing period, a final decision was made to accept or reject the potential subject and he was notified by the project director. (Any abnormal findings on the screening examinations were discussed with the individual by Drs. Gorman or Putnam and referred to their private physician for further follow up.)

A letter (see Appendix M) was then sent to the selected subjects providing information on general procedures, compensation, insurance coverage, routes, schedules, and safety information.

The project was discussed with 50 different bicyclists and 30 were interviewed and given a health questionnaire. Fifteen (15) potential subjects were referred by the project director to Drs. Gorman and Putnam for screening examinations and 11 were selected as study subjects (10 subjects and one alternate).

3.2 Description of Selected Subjects

Eleven (11) male subjects[a] (10 subjects and 1 alternate) ranging in age from 23-39 years of age were selected for the study. They were all college graduates and were either employed in professional occupations or were graduate students. All of the subjects worked each day in an air-conditioned environment. In addition to daily bicycle commuting (when possible), all of the subjects described themselves as physically active.

All of the subjects were non-smokers for the duration of the study. Nine of the subjects denied any smoking history. Subject B-6 had stopped smoking one and one-half years prior to the study and Subject M-2 had stopped smoking one month prior to the beginning of the study. Before that time he had smoked five cigarettes a day for the last one and one-half years.

One day before the testing began, Subject B-1 dropped out of the study for the stated reason of a change in his medical school commitments and he was replaced with the alternate who became Subject B-1.

All of the ten subjects maintained a high degree of motivation and enthusiasm during the testing period. They were very cooperative with the study team, even when testing was cancelled due to weather and re-scheduling became necessary.

(a) None of the female candidates passed the preliminary screening criteria.

All of the subjects maintained good physical and emotional health during the period of the study, except for Subject B-3, who experienced a severe knee injury not related to the study and was unable to complete his last two scheduled runs.

In addition to this injury, the use of this subject's data was complicated by an error in data collection during baseline and the first study run. A study team member observed that the subject was gripping the hand bars tightly during the maximal exercise testing. Because the study protocol did not permit use of the hand bars except for balance purposes, this subject agreed to repeat his baseline testing and Run Number 1 at the request of the study team. Repetition of Run Number 1 produced a change in treadmill time from 1,080 seconds to 855 seconds. His succeeding treadmill times were all within this range (720-880 seconds); thus the earlier inflated baseline and Run Number 1 values were deleted. Repeat of the baseline testing for this subject was scheduled near the end of the project to enable the subject to continue with his regular schedule of testing days and meet his other commitments. However, because of the serious knee injury, the subject was unable to complete his last two scheduled runs or the repeat of his baseline testing, and the raw data for the cardiovascular testing portion of the study could not be used for this subject. The other raw data for this subject, however, were determined to be reliable and valid for use in the study.

3.3 Physiological Testing Procedures

A number of different testing procedures were utilized during this study to determine changes in health status as the result of exposure to varying levels of pollutants under a variety of test conditions.

Vital signs (temperature, pulse, and respiration) were always taken before testing to assess the subject's general physical condition on that day. The subject weighed himself nude before and after the test run for data to assess the effects of thermal stress. A check of 11 signs and symptoms (cough, wheeze, sputum production, substernal pain, dyspnea, fatigue, headache, sore throat, laryngeal irritation, nasal discharge, and eye irritation) was made before and after every testing period to collect data on the relationship of pollutants to a change in health status.

Maximal multi-stage exercise testing was used to assess cardiovascular fitness and as an indirect measure of oxygen transport capacity following exposure to the pollutants and thermal stress (see Appendix K). Of the commonly used types of exercise procedures, the motor-driven treadmill is preferred simply because the work loads are regulated involuntarily. This test achieves a precision of energy expenditure not usually obtained with either step test or bicycle ergometer by individuals who are previously untrained. Better precision is obtained when exertion is performed without support of the handrail. Oxygen cost is thus directly related to the external work load which is standardized by the ergometer, the mechanical efficiency of the body, and the body weight. In laboratory tests involving several thousand ambulatory normal subjects and cardiac patients, the multi-stage treadmill test has been effective, expedient and remarkably reproducible.

Because the initial target of any air pollution is the respiratory tract, a number of pulmonary function tests were performed on the "Predictive Pulmonary Screener" (see Appendix L). In examining pulmonary function it is important to look at the performance of the central or large airways and the peripheral or smaller airways in comparison with the predicted norms.

The following tests of pulmonary function were administered and compared to the age predicted norms:

Forced vital capacity (FVC) refers to the volume of gas expelled with maximum expiration as forcefully and as rapidly as possible. This is an important standard measurement and is classified as an effort-dependent phenomenon.

Forced expiratory volume at one second (FEV_1) refers to the volume of gas exhaled over a given time interval (one second) during the performance of forced vital capacity. This is also an effort-dependent phenomenon and can be used as an indicator of air flow in the larger airways.

Forced expiratory volume at three seconds (FEV_3) is the same as above at three seconds.

Peak flow (PF) is the maximum level of expiratory flow and is another general indicator of airflow in the large airways.

Forced Expiratory Flow 25-75 ($FEF_{25-75\%}$) is the average rate of flow during the middle half of the forced expiratory volume. This is an effort-independent phenomenon which does not change significantly with additional effort and results can be used to reflect the properties of the lungs and small airways.

Forced expiratory flow at 50 percent of forced vital capacity (FEF_{50}) is an instantaneous flow measurement reflecting the performance of small airways and is relative to FEF 25-75 percent.

Blood samples were drawn before and after each testing period and sent to BioScience Laboratories for carboxyhemoglobin analysis (Appendix F). Because carboxyhemoglobin constitutes the toxic product formed during carbon monoxide inhalation, and is quite stable, it can be directly evaluated. This process determines whether an exposure has occurred, and the particular toxic concentration in the body.

3.4 Schedules

(1) Preliminary Schedule

The scheduling of the order in which data was to be collected was done in a random fashion through the use of a randomizing technique. Such a random determination of when each piece of data from a particular subject over a particular type and length of route is to be collected reduces the probability of bias that might occur if the collection of data was scheduled in any systematic manner.

(2) Actual Schedule

The data collection period extended from May 23 to July 22, 1977. Twenty-nine (29) total testing days were required to complete 78 test runs. Ten days were postponed and rescheduled due to rain or winds greater than 15 mph. There were five individual runs rescheduled due to subject illness (sore throat, colds) and two individual runs (one bicyclist and his control) rescheduled because of an unexpected business trip for the motorist control.

All subjects stayed within the time parameters for 30-minute runs $\pm$ 5 minutes and 60-minute runs $\pm$ 10 minutes, except for one subject on his first testing day who did not follow instructions and returned to the hospital early. This subject was rescheduled and repeated his route on another day.

All bicyclists ran their specified routes without deviation. On days of very high traffic density, certain routes tended to become difficult for the motorists to maneuver. On these days drivers ran shortened routes (eliminating one or more laps) to keep them within the imposed time limits. However, in no instance was a different path from the specified route taken during the testing period.

(3) Description of Testing Period

A summary of the average values of the pollution and weather measurements taken is presented in Table 3 on the following page. This table indicates a wide range of results, with average ozone concentrations exceeding the National Ambient Air One-Hour Secondary Standard (50 ppb), average carbon monoxide concentrations below the corresponding standard for CO (20 ppm) and a $32F^{o}$ temperature range during testing. The Washington Metropolitan Area experienced many pollution alerts (AQI greater than 100 for over a 24-hour period) during the testing period; a total of 11 of the testing days (38 percent) coincided with announced alerts.

TABLE 3

Summary of Measurements Made of Pollutants and Weather During the Period of Data Collection

	Mean	± S.D.	Range
Ozone Concentration, ppb	68	(±43)	10-200
CO Concentration (in situ), ppm	8.4	(±4.5)	0.9-21.0
Temperature, °F	85	(±8)	72-104
Relative Humidity, %	54	(±13)	25-90
[a] Soluble Sulfate Concentration, $\frac{\mu g}{m^3}$	22	(±10)	14-33 (n=9)
[a] Soluble Nitrate Concentration, $\frac{\mu g}{m^3}$	24	(±15)	4-70 (n=30)
[b] Total Particulates		Non-Detected	

(a) Mean of the detections: non-detections not considered

(b) Due to the low flow rate of the pumps, insufficient sample was collected on the filters to permit reporting of accurate on-site particulate levels (estimates of the mass of disposition on the filters range from .005 - .025 mg).

4. DESCRIPTION OF EXPERIMENTAL METHOD

On the day of testing, subjects were instructed to restrict all caffeine intake after 9 a.m., to eat a light lunch (defined as a sandwich and fruit juice), and encouraged to maintain a good fluid intake. Subjects who worked at the hospital reported directly to the testing area; the others were picked up at their place of work and transported to the George Washington University Medical Center by air-conditioned car.

Subjects stripped nude and weighed themselves and then dressed in gym shorts, t-shirt, belt, socks and athletic shoes. Temperature, pulse, and respiration were taken and the subject was interviewed and examined by a Registered Nurse who completed the symptom check list. A pre-exposure blood sample was also drawn for carboxyhemoglobin levels.

Subjects were then transported by air-conditioned car to their route starting point (for Routes X, Y, Z) or started at the hospital (Route W). The pumps were clipped to their belts and then the filters were clipped to the shoulders of their t-shirt. Filter intakes were configured closely to each subjects' breathing areas and were aligned in the same direction. Safety tips, route instructions, and maps were again reviewed and clipped to the front of the bike. Bicycle subjects were instructed to travel at 12 mph and breathe through their mouth whenever possible in order to receive the maximum effects of ambient particulate loading. Motorist subjects were instructed to travel at posted speed limits.

When the subject was ready, all pumps and a stopwatch (hanging around his neck) were turned on simultaneously and the test run began.

Meteorological measurements were then taken by a study team member at the route site consisting of wind speed, by use of a portable spring-loaded anemometer, and temperature and relative humidity by use of a sling psychrometer. These values, as well as previously obtained barometer pressure and airport-measured area wind speed and direction, were recorded on a data sheet on which also was logged the start/stop times of the pumps and their respective flow rates.

At the conclusion of the test run at George Washington University Medical Center, all pumps and stopwatches were turned off simultaneously. Equipment was quickly removed from the subject and he reported immediately to the testing area. All post-exposure testing started at four minutes past arrival time. Subjects completed the pulmonary function testing; temperature, pulse, and respiration were recorded; the symptoms check list was completed by the same pre-examiner; and a post-exposure blood sample was drawn for carboxyhemoglobin levels. The subject then stripped nude to weigh himself and dressed. This series of activities was always completed within 10 minutes of arrival time in the testing area.

At this point, the subject was allowed to drink a moderate amount of water, and then was given a maximal treadmill exercise test.

After completion of this test, subjects were checked for any side effects from the test runs or the testing procedures.

III. DATA ANALYSIS

1. HYPOTHESES, VARIABLES, MEASUREMENT TECHNIQUES, AND ANALYSIS PLAN

Exhibit 5 on pages 45 through 54 provides an overview of the study methodology. The related variables, data needed to measure these variables, measurement techniques and an analysis plan are provided for each of the following experimental hypotheses:

- Carbon monoxide levels monitored at permanent air monitoring stations are a predictor of the actual carbon monoxide levels experienced by bicyclists and motorists in an urban environment.

- Carbon monoxide levels experienced by bicyclists are equal to the carbon monoxide levels experienced by their motorist controls.

- Actual carbon monoxide levels experienced by bicyclists and motorists are a predictor of the actual levels of total soluble sulfates and total soluble nitrates experienced by bicyclists and motorists in an urban environment.

- The average venous carboxyhemoglobin post-exposure level is equal to the average venous carboxyhemoglobin pre-exposure level for bicyclists and motorists for each of the partitioning categories.

- The venous carboxyhemoglobin level in bicyclists and motorists is affected by the concentration of carbon monoxide to which the commuter is exposed and the length of time the commuter is exposed.

- Oxygen transport capacity, measured by exercise duration using a Bruce Protocol, is degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.

- The results of pulmonary screening tests are degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.

- A change in physical signs and symptoms occurs when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.

EXHIBIT 5

Data Analysis Plan

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
1. a. Carbon monoxide levels monitored at permanent air monitoring stations are a predictor of the actual carbon monoxide levels experienced by bicyclists and motorists in an urban environment. b. Carbon monoxide levels experienced by bicyclists are equal to the carbon monoxide levels experienced by their motorist controls.	$CO_C(g)$ is the average carbon monoxide concentration that the bicyclist or motorist is exposed to during trip "g"	The average concentration of CO in ppm that the bicyclist or motorist is exposed to during trip "g"	Sample of air is pumped into a bag at a fixed rate by pulse pump. At end of trip, bag contents are analyzed by passing sample through non-dispersive infrared analyzer. This provides average concentration of CO in ppm for trip.	I. Assessment of Impact a. Engineering Analysis The value of the dependent variable, average carbon monoxide that the subject was exposed to (CO_C) and the independent variable, average carbon monoxide concentration for the time during which a trip occurred, as measured by the closest permanent air monitoring station (CO_S) were arrayed as a function of the partitioning attributes of mode of transportation and route II. Identification of Influential Variables and Variable Relationships a. A simple linear regression is run in which the dependent variable is CO_C (g) and the independent variable is CO_S (g). This regression is based on 46 bicycle trips and provides an equation for predicting CO_C from CO_S. The equation's "predictive power" is assessed in terms of its R^2 and other statistical indicators
	$CO_S(g)$ is the average carbon monoxide concentration for the time during which trip "g" occurs, as measured by the closest permanent air monitoring station. $CO_S(g)$ is constructed from $\frac{1}{T_2(g)-T_1(g)} \int_{T_1(g)}^{T_2(g)} co(t)dt$ where co(t) is a continuous readout of CO in ppm and $T_2(g)$ and $T_1(g)$ are, respectively, the end time and start time of trip g.	The continuous concentration of CO in ppm over a period of time matched to the time when trip "g" occurred.	Continuous readout of CO concentration ppm is available from the permanent air monitoring station that is closest to the trip path.	

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
1. Continued				b. Part a. is repeated using the 24 automobile trips c. The regression equation derived in part a. for bicyclists is compared to the regression equation derived in part b. for motorists to determine if they are significantly different d. Part a. is repeated twice—once using 35 little or no traffic trips and once using 39 traffic trips e. Part a. is repeated twice—once using 39 little or no building trips and once using 39 high building density trips f. The predictive power of the regression equations is assessed by using Student's t test.

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
2. Actual carbon monoxide levels experienced by bicyclists and motorists are a predictor of the actual levels of total soluble sulfates, and total soluble nitrates experienced by bicyclists and motorists in an urban environment.	$CO_C(g)$ is the average carbon monoxide concentration that the bicyclist or motorist is exposed to during trip "g"	The average concentration of CO in ppm that the bicylist or motorist is exposed to during trip "g"	Sample of air is pumped into a bag at a fixed rate by pulse pump. At end of trip, bag contents are analyzed by passing sample through non-dispersive infrared analyzer. This provides average concentration of CO in ppm for trip	I. Assessment of Impact a. Engineering Analysis The values of the dependent variables, average total soluble sulfate concentration (TSS_V) and average total soluble nitrate concentration (TSN_V) that the subject is exposed to during trip (g) are arrayed as a function of mode of transportation and routes II. Identification of Influential Variables and Variable Interrelationships a. A series of two simple linear regressions is run in which the independent variable is CO_C (g) and the dependent variables are, respectively, TSS_V(g) and TSN_V (g). These regressions are each based upon 56 bicycle trips and provide two equations for predicting, respectively, total soluble sulfates and total soluble nitrates from carbon monoxide. Each equation's "predictive power" is assessed in terms of its R^2 and by using the Student's t test
	$TSS_V(g)$ is the average total soluble sulfates concenira-tion that the bicyclist or motorist is exposed to during trip "g"	The average concentration of total soluble sulfates in $\mu g/m^3$ that the bicyclist or motorist is exposed to during trip "g"	Vacuum Pump mounted on bicycle or automobile that draws air through a filter at a known rate for a known period of time. Filter is then chemically analyzed to obtain an average concentration of total soluble sulfates in $\mu g/m^3$ for the trip	
	$TSN_V(g)$ is the average total soluble nitrates concentration that the bicyclist or motorist is exposed to during trip "g"	The average concentration of total soluble nitrates in $\mu g/m^3$ that the bicyclist or motorist is exposed to during trip "g"	Vacuum Pump mounted on bicycle or automobile that draws air through a filter at a known rate for a known period of time. Filter is then chemically analyzed to obtain an average concentration of total soluble nitrates in $\mu g/m^3$ for the trip	
	N/A	N/A	N/A	

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
2. Continued				b. Part a. is repeated using the 24 automobile trips c. The regression equations derived in part a. for bicycles are compared to the regression equations derived in part b. for motorists to determine if they are significantly different d. Part a. is repeated twice - once using 28 little or no traffic bicycle trips and once using 28 traffic bicycle trips e. Part a. is repeated twice - once using 28 little or no buildings bicycle trips and once using 28 high building density bicycle trips f. The predictive powers of the regression equations are assessed by using Student's t test.

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
3.a. The average venous carboxyhemoglobin post-exposure level is equal to the average carboxyhemoglobin pre-exposure level for bicyclists and motorists for each of the partitioning categories.	$CO_C(g)$ is the average carbon monoxide concentration that the bicyclist or motorist is exposed to during trip "g"	The average concentration of CO in ppm that the bicyclist or motorist is exposed to during trip "g"	Sample of air is pumped into a bag at a fixed rate by pulse pump. At end of trip, bag contents are analyzed by passing sample through non-dispersive infrared analyzer. This provides average concentration of CO in ppm for trip.	I. <u>Assessment of Impact on Venous Carboxyhemoglobin Level of Carbon Monoxide</u> a. <u>Engineering Analysis - Variable Profile Method</u> The values of <u>all</u> dependent variables are arrayed as a function of partitioning variables (e.g., planned length of trip) and independent variables (e.g., average carbon monoxide concentration). <u>Patterns of change</u> in venous carboxyhemoglobin levels are identified II. <u>Identification of Influential Variables and Variable Interrelationships</u> a. <u>Regression</u> A set of linear regressions are run a number of times using $\Delta COHb(g)$ as the dependent variable. These runs are partitioned by planned length of trip and mode of transportation. The regressions' quality is assessed in terms of its R^2 and Student's t statistic
b. The venous carboxyhemoglobin level in bicyclists and motorists is affected by the concentration of carbon monoxide to which the commuter is exposed and the length of time the commuter is exposed.	$T(g)$ is the actual time in minutes to complete the trip	Trip elapsed time in minutes	Stopwatch	
	$\Delta COHb$ is constructed as the percent change in venous carboxyhemoglobin level from a pre-exposure measurement using the equation $\Delta COHb_g = COHb_g - COHb_B$ where $COHb_g$ is the venous carboxyhemoglobin level at the end of trip "g" and $COHb_B$ is the pre-exposure value, both in %	The venous carboxyhemoglobin level in percent measured at the <u>end</u> of trip " " The pre-exposure venous carboxyhemoglobin level measured for a single subject prior to trip "g"	Spectrophotometric analysis of venous blood for carboxyhemoglobin	

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
4. Oxygen transport capacity measured by exercise duration using a Bruce Protocol, is degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.	HR(g), which is the measured heart rate after trip "g" at peak during test HR_B, which is the baseline heart rate scale during test MAPHR, which is the maximum age predicted heart rate derived from the equation MAPHR = 220 - Age of Subject	Heart rate at peak during test after trip "g" Baseline heart rate at peak during test	Rate count ruler on EKG paper printout	I. <u>Assessment of Impact</u> a. <u>Engineering Analysis - Variable Profile Method</u> The values of all dependent variables are arrayed as a function of partitioning variables and as a function of independent variables. Patterns of change are identified II. <u>Identification of Influential Variables and Variables Interrelationships</u> a. <u>Regression</u> Stepwise multiple linear regressions are run using change in total elapsed time as the dependent variables and temperature, relative humidity, CO, ozone, total soluble sulfates and total soluble nitrates as the independent variables. The regression data is partitioned by length of trip and mode of transportation. The quality of the regression is assessed in terms of its R^2, F level and Student's t statistic.
	TET(g), which is the total elapsed time under the Bruce Protocol after trip "g" TET_B, which is the baseline total elapsed time under the Bruce Protocol	Total elapsed time under the Bruce Protocol after trip "g" Baseline total elapsed time under the Bruce Protocol	Motor driven treadmill with variable belt speed and grade	
	RTET(g), which is the percent change in total elapsed time for trip "g" $CO_C(g)$, $TSS_V(g)$, $TSN_V(g)$, and T(g) are as defined under earlier hypotheses OZ(g) is the average ozone concentration in ppm that the bicyclist or motorist is exposed to during trip "g"	Described under earlier hypotheses Average ozone concentration in ppm that the bicyclist or motorist is exposed to during trip "g"	Ozone concentration is available from the permanent air monitoring station that is closest to the trip path	

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
5. The results of pulmonary screening tests are degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.	PFVC(g) is the measured % of predicted Forced Vital Capacity (FVC) at the end of trip "g" $PFVC_B$ is the baseline % of predicted FVC RPFVC(g) = $\frac{PFVC(g)-PFVC_B}{PFVC_B} \bullet 100$	Computer readout from Predictive Pulmonary Screener indicating levels of Forced Vital Capacity (FVC) Percent of FVC (based on norms of Korey)	Predictive Pulmonary Screener	I. Assessment of Impact a. Engineering Analysis — Variable Profile Method The values of all dependent variables (the pulmonary function tests) are arrayed by partitioning attributes of route, trip length, and mode of transportation and by the independent variables of temperature, relative humidity, carbon monoxide, ozone, total soluble nitrates and total soluble sulfates
	$PFEV_1(g)$ is the measured % of predicted forced expiratory volume at one second (FEV_1) at the end of trip "g" $PFEV_{1B}$ is the baseline % of predicted FEV_1 $RPFEV_1(g)$ = $\frac{PFEV_1(g) - PFEV_{1B}}{PFEV_{1B}} \bullet 100$	Forced Expiratory Volume at one second (FEV_1) % of predictive FEV_1 (based on norms of Korey)		II. Identification of Influential Variables and Variable Interrelationships a. Correlation Among Independent Variables - A correlation matrix for all pulmonary variables is constructed and a reduced set of independent variables derived for various partitioning combinations b. Regression A series of stepwise multiplier linear regressions are run for the dependent variable against the independent variables for bicyclists and motorists and 30-min. and 60-min. trips

CONTINUED ON NEXT PAGE

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
5. Continued	Continued PPF(g) is the measured % of predicted PF at the end of trip "g" peak flow (PF) PPF_B is the baseline % of predicted PF RPPF(g) = $\frac{PPF(g) - PPF_B}{PPF_B} \bullet 100$	Measured peak flow at end of trip "g" ($PF_{(g)}$) % of predicted peak flow at end of trip "g" (based on norms of Morris)		b. Regression (continued) The quality of the regressions is assessed in terms of their R^2 and F levels
	$FEF_{50}(g)$ is the forced exp. flow at 50% of FVC measured at the end of trip "g" FEF_{50B} is the baseline FEF_{50} $RFEF_{50}(g)$ = $\frac{FEF_{50}(g)-FEF_{50B}}{FEF_{50B}} \bullet 100$	Forced Vital Capacity, Forced Expiratory Flow		

EXHIBIT 5 (Continued)

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
5. Continued	Continued $PFEF_{25-75(g)}$ is the % of predicted $FEF_{25-75\%}$ measured at the end of trip "g" $PFEF_{25-75B}$ is the baseline % of predicted $FEF_{25-75\%}$ $RPFEF_{25-75(g)} = \frac{(PFEF_{25-75(g)} - PFEF_{25-75B})}{PFEF_{25-75B}} \bullet 100$	Forced Expiratory Flow at 25-75% of total forced expiratory volume ($FEF_{25-75\%}$) Predicted forced expiratory flow at 25-75% of total forced expiratory volume (based on norms of Morris)		
	$CO_B(g)$, $TSS_V(g)$, $TSN_V(g)$, $T(g)$, and $OZ(g)$, and are as defined under earlier hypotheses.			

HYPOTHESIS	RELATED VARIABLES	DATA NEEDED TO MEASURE VARIABLE	MEASUREMENT TECHNIQUE	ANALYSIS PLAN
6. A change in physical signs and symptoms occurs when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.	The following signs and symptoms are mathematical constructs such that any deleterious change from beginning to end of trip "g" receives the value 1 and no change receives the value zero: COUGH (g) = Cough WHEEZ(g) = Wheeze SPUTM(g) = Sputum SUBST(g) = Substernal pain DYSPN(g) = Dyspnea FATIG(g) = Fatigue HEAD(g) = Headache THROT(g) = Sore throat LARYN(g) = Laryngeal irritation NASAL (g) = Nasal discharge EYE (g) = Eye irritation $CO_C(g)$, $TSS_V(g)$, $TSN_V(g)$, T(g), and OZ(g), and are as defined under earlier hypotheses.	Symptom scoring on a scale from 0 (none) to 3 (severe) by subject (subjective) and health professional (objective) before and after each trip "g"	Subjective reports Objective observations	I. Assessment of Impact a. Engineering Analysis The values of all dependent variables (signs and symptoms) are arrayed as a function of the mode of transportation and planned length of trip b. Statistical Analysis A series of Chi Square contingency tables are patterned using a discrete level of positive symptom change vs. a tri-partite set of ozone concentration levels and nitrate concentration levels.

2. RESULTS AND DISCUSSION OF DATA ANALYSIS

2.1 Hypotheses 1a and 1b

Hypotheses 1a and 1b are defined as follows:

- Hypothesis 1a—Carbon monoxide levels monitored at permanent air monitoring stations are a predictor of the actual carbon monoxide levels experienced by bicyclists and motorists in an urban environment.

- Hypothesis 1b—Carbon monoxide levels experienced by bicyclists are equal to the carbon monoxide levels experienced by their motorist controls.

In this study, Hypothesis 1a was not proved and Hypothesis 1b was proved.

(1) Background of Hypotheses 1a and 1b

It has been suggested that carbon monoxide concentrations, as monitored by fixed sampling stations, can be used to estimate remotely experienced CO levels: Kleiner and Spengler[3], in a study performed in Boston, advocate the use of this procedure. Vidmar[4], Kahn[5], and others have also used ambient CO data acquired from monitoring stations to examine population carboxyhemoglobin levels on a comparative basis. Gilmore[6], Godin[7], Cortese[8], and others, however, have objected to the assertion that fixed stations are a method of determining in situ CO levels accurately. Cortese noted a consistent underestimation of actual exposure and explained the cause as factors relating to CO dispersion and height of the station's sampling

probe (15 feet). Godin presented data showing drops in CO concentration of as much as 7 ppm only 20 feet away from a highway source, with much variability in the data. Finally, Gilmore suggested that personal CO monitoring may be necessary on the basis of work showing that COHb levels are more closely correlated with localized sources of CO (such as work environments) rather than ambient levels of CO.

(2) Discussion of Hypotheses 1a and 1b

Personal exposure data, disaggregated by modes of travel and routes are summarized in Table 4 on the following page. In this table, CO_S refers to the average carbon monoxide concentration measured by the closest permanent air monitoring station, and CO_C is the average carbon monoxide that the bicyclist or motorist was exposed to *in situ.*

These data display a much greater variability and magnitude of exposure in the CO levels measured *in situ* as compared to those measured by the West End Library Station. The underestimation of street-sited CO by the station is consistent, and sometimes off from those values by over 15 ppm: the range of *in situ* values is 0.9-21.0 ppm with a mean of 8.4 ± 4.5 ppm, whereas the range of corresponding values obtained from the station is 1.0-2.5 ppm, mean value = 1.1 ± .2 ppm.

Also, the variance in CO levels within the confines of the traffic stream is sufficiently small such as to suggest that motorists and bicyclists are exposed to equivalent amounts.

TABLE 4

Mean Concentrations of Carbon Monoxide Station (CO_S) and Carbon Monoxide Collected (CO_C), ppm

Partitioning Attributes	Number of Cases	CO_S	CO_C
W_M	6	1.0 $\pm$0.0	7.7 $\pm$ 3.8
X_M	6	1.0 $\pm$0.0	6.9 $\pm$ 2.7
Y_M	6	1.6 $\pm$0.7	9.8 $\pm$ 5.2
Z_M	5	1.1 $\pm$0.2	11.6 $\pm$ 3.5
W_B	13	1.0 $\pm$0.0	7.7 $\pm$ 4.8
X_B	13	1.0 $\pm$0.0	8.0 $\pm$ 2.1
Y_B	14	1.2 $\pm$0.1	7.5 $\pm$ 4.8
Z_B	12	1.2 $\pm$0.2	9.7 $\pm$ 6.0
All Bicyclists	52	1.1 $\pm$0.1	8.2 $\pm$ 4.6
All Motorists	23	1.2 $\pm$0.3	8.9 $\pm$ 4.1
All Cases	75	1.1 $\pm$0.2	8.4 $\pm$ 4.5

Analysis by route shows a deviation from the expected pattern of results. Whereas Routes Y and Z were designed to present the least amount of pollutant burden to the bicyclists and motorists on the basis of traffic volume and building density, they actually proved to be the greatest sources of CO. Closer inspection of the routes' layouts and subsequent interviews of the subjects revealed that unforeseen traffic delays on nearby streets caused long waits at certain intersections within the routes. In the case of Route Y, the 14th Street connector tended to become clogged with traffic, much of which was comprised of buses. Mobility

was often hampered at the 21st Street and New Hampshire Avenue intersection of Route Z, sometimes resulting in delays up to five minutes before a crossing could be made. Thus, although for the greatest part, these routes were characterized by relatively low traffic volume, at certain intersections traffic volume was much higher and slow moving. It is important to note that idling or slowly moving automobiles tend to generate high CO emissions, averaging 20,000 ppm (over 2 percent) at the tailpipe[9]. This helps to explain the CO values when partitioned by route.

In order to test Hypothesis 1a, a simple linear regression was run in which the dependent variable was CO_C and the independent variable was CO_S.

The first regression was based on 54 bicycle trips and was then repeated using 24 automobile trips, yielding the equation in the following form:

$$\left[CO_C\right] = a + b \left[CO_S\right] .$$

The regression was again repeated using the partitioning attributes of 39 low volume traffic trips, 39 high volume traffic trips, 39 low building density trips, and 39 high building density trips.

The predictive power of the equation was assessed by testing Hypothesis 1a, that the carbon monoxide levels experienced by the bicyclists and/or motorists (CO_C) are independent of the levels of carbon monoxide monitored at the nearest permanent air monitoring station (CO_S). This was accomplished by using Student's t test to determine

whether or not the slope of the regression equation (b) is equal to zero (i.e., whether or not variable CO_C and the variable CO_S are independent).

Table 5 below presents the results of this test for each regression equation. In all cases, the value of t indicates that at the 95 percent level of significance, the hypothesis that b = 0 and that the variable CO_C is independent of the variable CO_S was proved. Therefore, the hypothesis was not proved that carbon monoxide levels monitored at the nearest permanent air monitoring station are a predictor of the actual carbon monoxide levels experienced by bicyclists and motorists.

TABLE 5

Regression: $[CO_C]$ vs. $[CO_S]$

$$CO_C = a + b\ CO_S$$

Partitioning Attribute	Number of Cases	b	t	t(.95)[a]	r	CO_C[b]
Bicyclists	54	-.63	-.77	- 1.72	.03	8.9
Motorists	23	-.32	-.16	- 1.67	.51	7.6
High Volume Routes (W, X)	39	0	--	---	0	---
Low Volume Routes (Y, Z)	37	-.68	-.45	- 1.68	.58	9.1
High Density Routes (W, Z)	36	-5.1	-1.9	- 1.68	.61	8.9
Low Density Routes (X, Y)	39	.24	-.20	- 1.68	.83	7.9

(a) Value of t required to prove Hypothesis 1a at the 95 percent level of significance

(b) Average CO_C concentration, ppm

In order to test Hypothesis 1b, that the average carbon monoxide level experienced by bicyclists was equal to the average carbon monoxide level experienced by the motorist controls for those bicyclists, Student's t test (on a pair-wise basis) was used.

Table 6 below presents the results of this test for all paired bicyclist and motorist runs, for Routes W through Z (routes were not partitioned by time because CO is not a time dependent phenomenon). In all cases the value of t indicates that at the 95 percent level of significance, the hypothesis was proved that the average carbon monoxide level experienced by bicyclists was equal to the average carbon monoxide level experienced by the motorist controls for those bicyclists.

TABLE 6

Paired t-Test: Carbon Monoxide Levels Experienced by the Motorists Compared to Those of the Controlled Bicyclists

Partition	Number of Cases	Motorists $\overline{CO}_C$, ppm	Bicyclists $\overline{CO}_C$, ppm	t	t(.95)[a]
Route W	6	7.7	7.7	.74	2.02
Route X	5	6.8	10.6	-1.50	-2.13
Route Y	6	9.8	7.5	1.90	2.02
Route Z	4	12.7	14.0	-0.34	-2.35

(a) Maximum value of t required to prove Hypothesis 1b at the 95 percent level of significance

In summary, in this preliminary study, the levels of CO measured at monitoring stations were found to be unrelated to the values of CO actually present in the mainstream of traffic. This phenomenon results in large part from the complexity of Washington's street layout, which makes it difficult for the station, which reflects CO levels from a variety of street sources, to obtain concentration data that can be applied to specific areawide subdivisions. Work by Gilmore, Cortese, Godin and many others supports this conclusion.

(3) Findings of Hypotheses 1a and 1b

The findings of Hypotheses 1a and 1b were:

- CO levels monitored at the permanent air monitoring station utilized in this study were consistently lower than the actual CO levels experienced by the bicyclists and motorists participating in this study.

- CO levels experienced by bicyclists were approximately the same as those experienced by their motorist controls travelling the same routes at the same times while participating in this study.

2.2 Hypothesis 2

Hypothesis 2 is defined as follows:

- Actual carbon monoxide levels experienced by bicyclists and motorists are a predictor of the actual level of total soluble sulfates and total soluble nitrates experienced by bicyclists and motorists in an urban environment.

This hypothesis was not proved in this study.

(1) Background of Hypothesis 2

Suggestions have been made that indicate the possibility of a relationship between CO and other automobile emissions, such as sulfates and nitrates[10, 3]. Sulfur is present in standard gasolines in quantities of several hundredths percent by weight[10, 11], and oxidized to sulfuric acid directly in cars equipped with catalytic converters. Sulfates are also formed in a secondary fashion by oxidation of emitted SO_2 (sulfur dioxide) by oxidants present in the atmosphere—especially those associated with photochemical smog. Nitrates are formed in a similar manner by a secondary process involving oxidation of exhausted NO_2 (nitrogen dioxide) by atmospheric radicals (such as $OH^{\cdot}$) that generates nitric acid. Nitric acid, while extremely corrosive, is rapidly removed via reaction with ambient suspended particles that convert it to nitrate species.

(2) Discussion of Hypothesis 2

Personal exposure data were first arrayed as a function of the individual routes. Table 7 below presents these data.

TABLE 7
Mean Concentrations: Nitrates, Sulfates and Carbon Monoxide

Route	% of Cases (a)	TSN $\frac{\mu g}{m^3}$ (b)	% of Cases	TSS $\frac{\mu g}{m^3}$ (c)	% of Cases	CO_C ppm (d)
W	35	20 ± 9	15	22	95	7.7 ± 4.4
X	35	21 ± 9	5	15	95	7.5 ± 2.4
Y	40	21 ± 13	10	10	95	8.0 ± 5.0
Z	35	30 ± 19	15	33	90	10 ± 5

(a) Represents the percentage of detections relative to the total possible number per category (100% = 20 cases) (b) Total soluble nitrates
(c) Total soluble sulfates (d) Carbon monoxide - collected

In order to test this hypothesis, a series of two simple linear regressions was run in which the independent variable (CO_C) was the average carbon monoxide concentration that the bicyclist and motorist was exposed to during a trip and the dependent variables were respectively, TSS_V, the average total soluble sulfates concentration that the bicyclist and motorist was exposed to during a trip, and TSN_V, the average total soluble nitrates concentration that the bicyclist and motorist was exposed to during a trip.

The regressions were based upon the total number of cases where TSN and/or TSS were detected and provided two equations:

$$TSN_V = a + b \left[CO_C\right]$$

$$TSS_V = a + b \left[CO_C\right]$$

for predicting total soluble nitrates and total soluble sulfates.

The predictive power of the equations was assessed by using Student's t test to determine whether or not the slope of each regression equation (b) is equal to zero (i.e., whether or not the variable TSS and the variable CO_C are independent and whether or not the variable TSN and the variable CO_C are independent).

Table 8 on the following page presents the results of this test for each regression equation.

In the case of total soluble nitrates, the value of t indicates that at the 95 percent level of significance, the hypothesis was proved that b = 0 and that the variable TSN is independent of the variable CO_C (in those cases where

TABLE 8

Results of Regressions: Measured Total Soluble Nitrates (TSN) on Measured Carbon Monoxide (CO) and Measured Total Soluble (TSS) on Measured Carbon Monoxide

Regression	Number of Cases	Average Concentration Dependent Variable ($\mu g/m^3$)	Standard Error of Estimate	b	t	$t(.95)^{(a)}$	R^2
TSN on CO_C	29	24	15	+0.23	-0.08	-1.76	.00
TSS on CO_C	9	22	6	-1.41	3.50	2.02	.61

(a) Value of t required to prove Hypothesis 2 at the 95 percent level of significance

TSN was detectable). Therefore, the hypothesis was not proved that actual carbon monoxide levels experienced by bicyclists and motorists are a predictor of the actual levels of total soluble nitrates experienced by bicyclists and motorists (in those cases where TSN was detectable).

In the case of total soluble sulfates, the value of t indicates that at the 95 percent level of significance, the hypothesis that b = 0 was not proved and that the variable TSS is not independent of the variable CO_C (in those cases where TSS was detectable). Therefore, the hypothesis was tentatively proved that the actual carbon monoxide levels experienced by bicyclists and motorists are a predictor of the actual levels of total soluble sulfates experienced by bicyclists and motorists (in those cases where TSS was detectable). Due to the small number of detectable observations for nitrates and sulfates, however, additional statistical analysis was done to further examine possible relationships among these variables using detectable and non-detectable data.

The values for TSN and TSS were divided into two categories: detectable levels and non-detectable levels; also, the values for CO_C were divided into two categories: levels below 6 ppm and levels above 6 ppm. A two-way classification table was then constructed for TSN and CO_C and for TSS and CO_C, and the χ^2 test was used to test the hypothesis that the levels of TSN are independent of the levels of CO_C (for both detected and non-detected levels of TSN) and that the levels of TSS are independent of the levels of CO_C (for both detected and non-detected levels of TSS).

Table 9 below presents the results of this test for each two-way classification.

TABLE 9

Results of Tests of Independence (χ^2): Total Soluble Nitrates (TSN) vs. Carbon Monoxide - Collected and Total Soluble Sulfates (TSS) vs. Carbon Monoxide - Collected (CO_C)

Two-Way Classification	Cases	χ^2	$\chi^2(.95)$[a]	Degree of Freedom
TSN vs. CO_C	75	0.03	3.84	1
TSS vs. CO_C	76	0.04	3.84	1

(a) Value of χ^2 required to prove Hypothesis 2 at 95 percent level of significance

The value of χ^2 indicates that at the 95 percent level of significance, the hypothesis is proved that the levels of TSN are <u>independent</u> of the levels of CO_C and that the levels of TSS are <u>independent</u> of the levels of CO_C.

In summary, our results show a lack of clear-cut relationship between in situ CO concentrations and either nitrate or sulfate concentrations.

The apparent lack of relationship may result from differences in the chemical processes which form these substances. CO is a primary pollutant emitted directly from the tailpipes of fossil-fuel powered engines. Its production is dependent solely upon engine operating parameters (such as leaness of air-to-fuel ratio and operating temperature). Nitrate has never been shown to be present in automobile exhaust in appreciable concentrations because it is primarily a secondary pollutant formed by reaction of certain engine-exhausted species (atmospheric oxidants and radicals). Thus, there is a time lag between formation of nitrate from emitted NO_2. In addition, NO_2 is reduced by the action of sunlight (a basic step in the production of smog), further slowing its conversion to nitrate.

Similarly, sulfate production requires a time lag that is not directly paired with CO production. However, sulfate may potentially be produced very rapidly under favorable conditions in the presence of a catalytic converter. The unpredictability of these conditions and the larger number of non-converter equipped cars make a correlation of sulfate concentration to CO concentration unreliable. SO_2 production is also associated with stationary sources (such as power plants), making a correlation of CO levels to its eventual atmospheric form (sulfate) even more difficult.

This conclusion is based on the levels of CO encountered in this study and cannot necessarily be used in other circumstances. Everett[12] has cited sources correlating particulates and high levels of CO. Ayres[13], however, reports that this conclusion may be questionable, based on a study in New York City in which CO levels did not change significantly over the period 1968-1972, while particulate and sulfur dioxide levels declined steadily in the same period of time.

(3) Findings of Hypothesis 2

Actual CO levels experienced by bicyclists and motorists participating in this study are not a valid predictor of the actual levels of total soluble sulfates and total soluble nitrates experienced by these same subjects.

2.3 Hypotheses 3a and 3b

Hypotheses 3a and 3b are defined as follows:

- Hypothesis 3a—The average venous carboxyhemoglobin post-exposure level is equal to the average venous carboxyhemoglobin pre-exposure level for bicyclists and motorists for each of the partitioning categories.
- Hypothesis 3b—The venous carboxyhemoglobin level in bicyclists and motorists is affected by the concentration of carbon monoxide to which the commuter is exposed and the length of time the commuter is exposed.

In this study, Hypothesis 3a was proved for some partitioning categories and Hypothesis 3b was not proved.

(1) Background of Hypotheses 3a and 3b

Cellular oxygen transport in humans is mediated entirely by attachment of oxygen molecules to circulating hemoglobin molecules. Hemoglobin is a protein also capable of binding other molecular species such as NO and CO. Its affinity for CO is 210 times that of its affinity for oxygen; thus, carboxyhemoglobin, or COHb, is thermodynamically much more stable than its oxygenated counterpart. In terms of oxygen transport and cellular uptake, COHb deprives tissues of oxygen nourishment and can remain in the bloodstream in this detrimental form for several hours[14].

A great deal of work has been done clinically to quantify the effect of COHb formation on oxygen transfer to tissues. Haak[15] demonstrated a decrease in maximal exercise performance at venous COHb concentrations of 5 percent; Gliner[16] found a similar effect in an extensive survey of thermal pollution-induced stress.

The major source of CO globally is from fossil-fuel powered equipment[17]. Thus, traffic volume and environment contribute directly to COHb formation. Medical investigation shows that heavy work can increase CO uptake (with a subsequent increase in venous COHb concentration) by as much as a factor of three[18] (limited by the increase in respiration), thus potentially causing bicyclists in a traffic stream to experience higher levels of COHb.

(2) Discussion of Hypotheses 3a and 3b

In order to test these hypotheses, an engineering analysis-variable profile method was completed and patterns of change in venous carboxyhemoglobin levels were identified. Table 10 on the following page illustrates the mean increase in carboxyhemoglobin, the mean exposure levels of carbon monoxide, and the mean post-exposure carboxyhemoglobin levels.

Pre-exposure and post-exposure carboxyhemoglobin levels were then arrayed (see Appendix A, Exhibit 8), and a comparison was made hypothesizing that the average carboxyhemoglobin post-exposure level is equal to the average carboxyhemoglobin pre-exposure level for each of the partitioning categories. Student's t test (on a pair-wise basis) was used to test these hypotheses.

Table 11 on page 71 presents the results of this test for each of the partitioning categories. The value of t indicates that at the 95 percent level of significance, the hypothesis that the average carboxyhemoglobin post-exposure level is equal to the average carboxyhemoglobin pre-exposure level was not proved for the following cases:

- All 60-minute runs
- All 60-minute bicycle runs
- All 30-minute automobile runs
- All automobile runs
- All 60-minute bicycle runs for Routes W and X combined

TABLE 10

Mean Increase in Carboxyhemoglobin Level (COHb) vs. Mean Exposure Levels of Carbon Monoxide; Mean Post-Run COHb Levels

PARTITIONING ATTRIBUTE						
Mode	Route/Time	# of (a) Cases	Mean COHb Elevation, %	Mean CO Exposure, ppm	# of (b) Cases	Mean Post-Run COHb, %
Bicycle	(All)	50	0.9 ± 0.7	8.3 ± 4.6	54	1.3 ± 0.4
Automobile	(All)	20	1.5 ± 1.1	9.3 ± 4.2	24	1.9 ± 1.3
Bicycle	60 minute	26	0.9 ± 0.8	9.2 ± 5.8	28	1.3 ± 1.0
Automobile	60 minute	9	1.7 ± 1.0	9.6 ± 4.3	12	1.8 ± 1.4
Bicycle	30 minute	24	1.1 ± 0.9	10.0 ± 4.0	26	1.3 ± 0.8
Automobile	30 minute	11	1.1 ± 0.7	8.0 ± 3.8	12	2.0 ± 1.2
Bicycle	Route W	14	0.9 ± 0.8	8.3 ± 5.0	13	1.6 ± 0.9
Automobile	Route W	5	1.6 ± 1.2	9.3 ± 4.7	6	1.4 ± 1.1
Bicycle	Route X	13	0.9 ± 0.8	8.6 ± 2.3	13	1.0 ± 0.8
Automobile	Route X	4	1.8 ± 1.5	8.3 ± 3.5	6	1.7 ± 1.4
Bicycle	Route Y	12	0.9 ± 0.7	8.2 ± 5.3	14	1.1 ± 0.8
Automobile	Route Y	5	2.5 ± 1.8	12.0 ± 6.0	6	2.3 ± 1.5
Bicycle	Route Z	11	1.0 ± 0.8	10.0 ± 6.0	13	1.4 ± 1.2
Automobile	Route Z	6	1.1 ± 1.0	14.0 ± 5.0	6	2.3 ± 1.4

(a) Negative change COHb levels not used
(b) All cases

TABLE 11

t -Test for Carboxyhemoglobin Change: Pre-Run vs. Post-Run (COHb)

Mode[a]	Duration[b]	Volume[c]	Density[d]	# of Cases	t	t (.95)[e]
B + M	60 + 30	H + L	H + L	78	0.38	1.67
B + M	30	H + L	H + L	38	0.18	1.68
B + M	60	H + L	H + L	40	3.60	1.68
B	30	H + L	H + L	26	0.09	1.71
B	60	H + L	H + L	28	3.80	1.70
M	30	H + L	H + L	12	3.80	1.80
M	60	H + L	H + L	12	1.60	1.80
B	60 + 30	H + L	H + L	54	0.22	1.67
M	60 + 30	H + L	H + L	24	3.20	1.71
B	30	H	H + L	13	0.07	1.78
B	60	H	H + L	14	3.00	1.77
M	30	H	H + L	6	0.18	2.02
M	60	H	H + L	6	0.59	2.02
B	30	L	H + L	13	0.44	1.78
B	60	L	H + L	14	2.40	1.77
M	30	L	H + L	6	4.00	2.02
M	60	L	H + L	6	1.70	2.02
B	60	H	H	7	1.80	1.94
B	60	H	L	7	1.90	1.94
B	60	L	L	7	1.60	1.94
B	60	L	H	7	1.50	1.94

(a) B = bicyclist, M = motorist
(b) Minutes
(c) Traffic volume: H = high, L = low
(d) Building density: H = high, L = low
(e) Value of t required to prove Hypothesis 3a at the 95 percent level of significance

- All 60-minute bicycle runs for Routes Y and Z combined

- All 30-minute automobile runs for Routes Y and Z combined

- All 60-minute bicycle runs for Route X.

The value of t indicates that at the 95 percent level of significance, the hypothesis of equal averages was proved for the remaining cases.

In order to try to determine the causes for the carboxyhemoglobin differences that did occur in some of the partitioning attributes (Hypothesis 3b), a simple (bivariate) linear regression was also run using the increase in venous carboxyhemoglobin levels (ΔCOHb) as the dependent variable and carbon monoxide in situ (CO_C) as the independent variable. The linear regression was performed for the following cases:

- All 60-minute runs
- All 30-minute runs
- All bicyclists
- All motorists
- All 60-minute bicyclists runs.

The predictive power of the equation was assessed by testing the hypothesis that ΔCOHb is independent of CO_C. This was accomplished by using Student's t test to determine whether or not the slope of the regression equation (b) is equal to 0 (i.e., whether or not the variable ΔCOHb and the variable CO_C are independent).

Table 12 below presents the results of this test for each regression equation.

TABLE 12

Results of Regression: Increase in Carboxyhemoglobin Level (ΔCOHb) and Carbon Monoxide - Collected (CO_C)

Partitioning Attributes	Number of Cases	Average[(a)] ΔCOHb	Standard Error of Estimate	t	t(.95)[(b)]	R^2
All 60-minute	34	0.98	1.00	-0.11	-1.69	.96
All 30-minute	30	0.91	0.67	-0.55	-1.70	.98
All Bicyclists	45	0.96	0.80	0.77	1.68	.98
All Motorists	19	1.30	1.10	-0.10	-1.73	.93
60-minute Bicyclists	22	0.75	0.72	1.30	1.72	.08

(a) ΔCOHb negative values not used

(b) Value of t required to prove Hypothesis 3b at the 95 percent level of significance

In all cases, the value of t indicates that at the 95 percent level of significance, the hypothesis was proved that b = 0 and that the variable ΔCOHb is independent of the variable CO_C. Therefore, we have been unable to demonstrate a relationship between changes in venous carboxyhemoglobin and the levels of carbon monoxide to which bicyclists and motorists were exposed while travelling on four different routes during this study.

In summary, the results of this preliminary study display a lack of statistical relationships between in situ CO exposure and eventual COHb formation for all partitioning attributes examined in this study (time, mode, route). Consistent minor elevations in COHb were observed, however, for the longer bicycle runs and the shorter automobile runs.

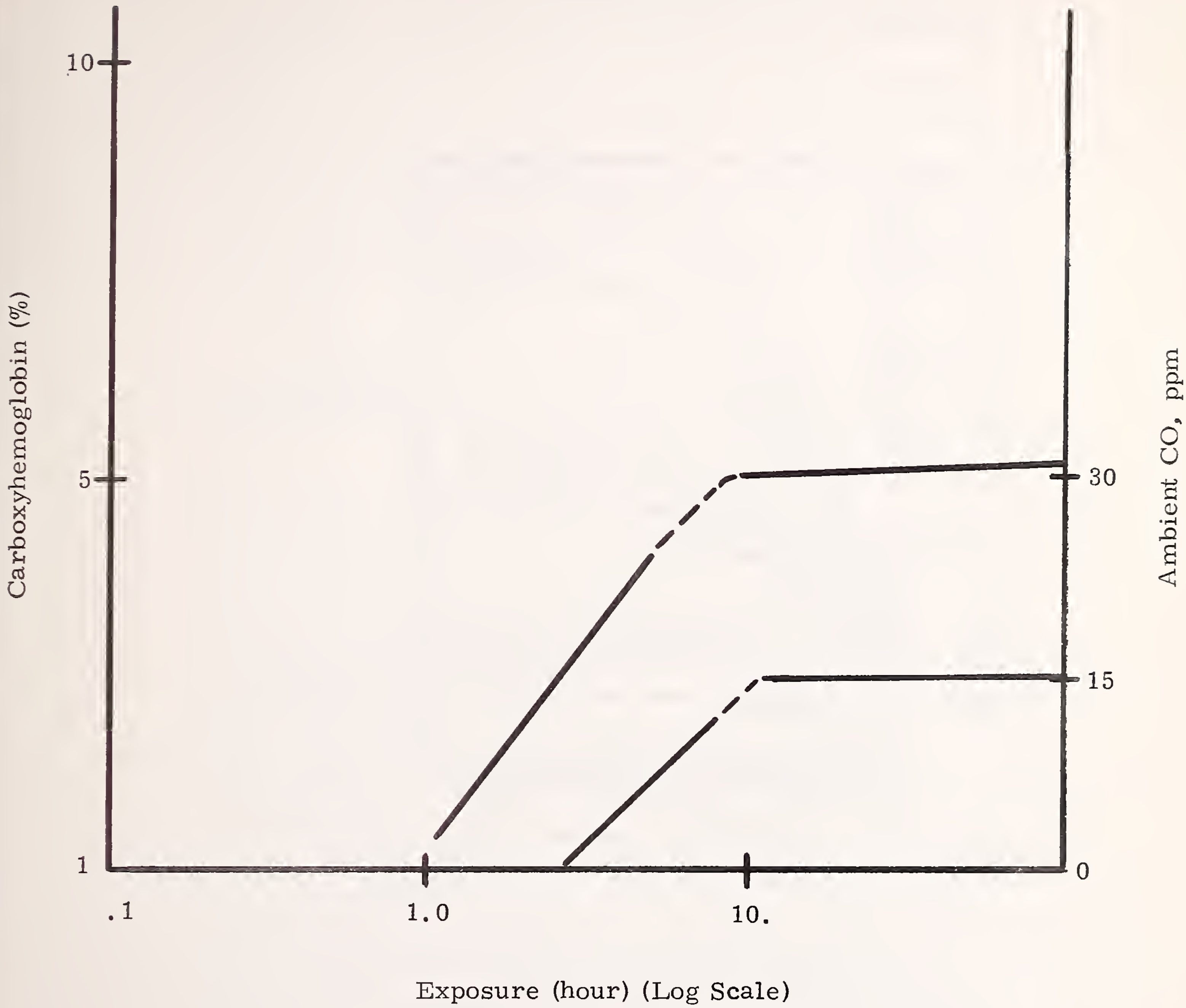
This lack of correlation between CO and COHb has been noted before[7,8]. Research[18,19] has shown that at levels of CO less than 30 ppm (encountered in this study), adults at moderate activity may require as many as four hours to come to an equilibrium COHb concentration, usually of 5 percent (see Figure 2 on the following page). At ambient levels of 15 ppm, 10 hours of continuous exposure will be necessary to produce venous COHb levels of even 3 percent (see Figure 2 on page 75). Absorption of low levels of CO into the bloodstream is a non-linear process, which may account for the lack of equilibrium between CO and COHb in this study.

The literature provides other support for a lack of relationship. Godin[7] observed that a 0.4 percent venous COHb increase would require a 40-minute drive if ambient CO concentrations were at 20 ppm. (The mean increases in this study ranged from 0.9 percent for motorists to 1.5 percent for bicyclists.) Cortese[8] could find no relationship between ambient levels of CO (11.9 $\pm$ 5.5 ppm) and subsequent concentration of COHb in a study of 66 non-smoking Boston commuters (average commuting time was one-hour), citing the low, fluctuating CO levels as a possible reason.

In comparing the results of Hypothesis 3b, examination of the data reveals that the motorists had a higher COHb level by a mean percentage difference of 0.6 percent than the bicyclists, even though their CO exposure differences were generally negligible. On Route Y, COHb levels were particularly high with a difference of 1.6 percent. Two possible explanations may account for this finding.

FIGURE 2

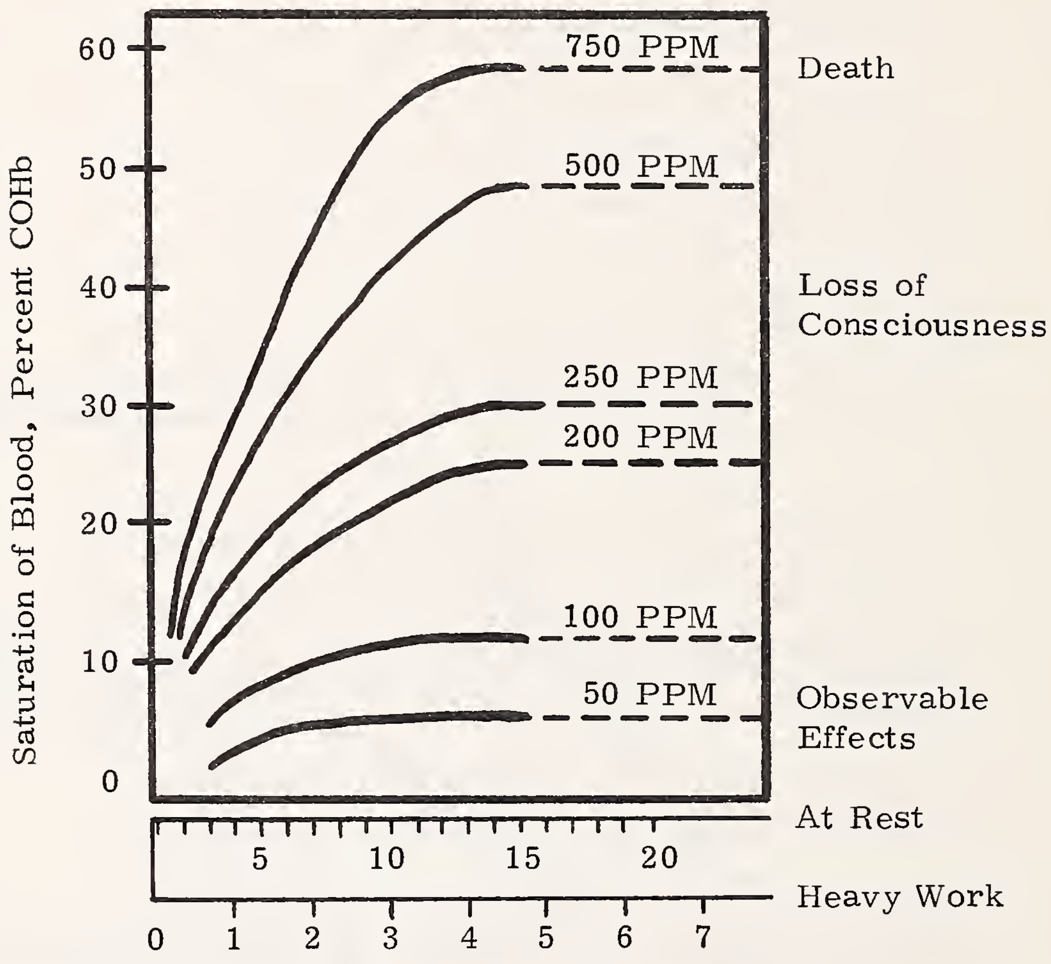
CO Uptake at Low Ambient Levels



Source: Agnew, W., Proceedings of the Royal Society, A307, 153, 1968.

FIGURE 3

Formation Rates of COHb at Different Work Loads



Duration of Exposure, Hours

Source: Wolf, P. C., Environmental Science and Technology 5:3, 1971, p. 213.

First, the motorists were far less mobile than the bicyclists. Whereas a bicyclist could avoid a major source of pollution (such as a bus or a crowded intersection) by travelling to the front of the vehicles, a motorist was more confined to his location in the traffic. Thus, at intersections, where CO concentration was likely to be much higher than the average for the route, the motorist was more likely to be exposed for longer periods of time.

Concentrations of CO greater than 500 ppm can raise bloodstream COHb levels up to 4 percent in less than five minutes (see Figure 3 on page 76). Once COHb is formed, it dissociates very slowly, so that sudden increase of COHb would remain essentially unchanged throughout the trip; at the same time the resulting grab-bag concentration of CO would be quite small in comparison. To obtain a 2.5 percent increase, it is necessary only to be exposed to a level of 500 ppm CO for 3 minutes (see Figure 3). Such exposure would result in a bag uptake of less than 30 ppm over an hour run, assuming ambient levels of CO elsewhere were 8 ppm. However, this hypothetical case is not intended to be taken as sole cause of the resulting distribution. Other possible explanations for the difference in mean COHb elevation between the motorists and bicyclists include the potential unreliability of measuring COHb levels at less than 2 percent, the very small number of cases included in this study, and the high standard deviation of the values in Table 10.

(3) <u>Findings of Hypotheses 3a and 3b</u>

The findings of Hypotheses 3a and 3b were:

- The average venous carboxyhemoglobin post-exposure level was greater than the average venous carboxyhemoglobin pre-exposure level for bicyclists and motorists for some of the partitioning categories while participating in this study.

- COHb levels experienced by the bicyclists and motorists in this study were not related to the levels of CO <u>in situ</u> or the length of exposure time encountered in this study.

It was also observed that:

- COHb levels measured for motorist controls were slightly higher than those encountered in the bicyclists who participated in this study.

- Traffic slow-downs or intersection delays may have had more impact on increasing levels of COHb than the low levels of CO encountered by the bicyclists and motorists while traveling the different designated routes of this study.

- Mean COHb post exposure levels were 2.1 percent for motorists and 1.7 percent for bicyclists, for the entire set of partitioning attributes, well below the daily levels of 4-6 percent encountered in smokers who smoke 1-2 packs of cigarettes a day.[20]

- Levels of measured CO in this study never exceeded the National Primary Standard (one-hour) for ambient air (35 ppm).

- Levels of ozone measured in this study had a wide range of values and exceeded the National Primary Standard for ambient air (80 ppb, one-hour) in 30 of the test runs (38 percent).

2.4 Hypothesis 4

Hypothesis 4 is defined as follows:

- Oxygen transport capacity measured by exercise duration is degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.

This hypothesis was not proved during this study.

(1) Background of Hypothesis 4

Extensive research has been done on the effects of carbon monoxide on the oxygen transport system. Exercise tolerance (measured in exercise duration) is considered to be an indirect measure of oxygen transport capacity and the effects of carbon monoxide can be readily shown.

Aronow and Cassidy[21] studied the effect of breathing 100 ppm of CO versus purified air for one hour on middle-aged healthy non-smokers and reported that the mean exercise time until exhaustion significantly decreased from 697.7 to 662.7 after breathing CO, and insignificantly increased from 694.9 to 703.4 after breathing purified air. COHb levels significantly increased from 1.67 percent to 3.95 percent after breathing CO and significantly decreased from 1.63 percent to 1.30 percent after breathing purified air. They concluded that increased COHb levels of the magnitude encountered after smoking or heavy atmospheric pollution impaired exercise performance in normal persons.

A study by Haak[15] demonstrated that carboxyhemoglobin levels of 5 percent significantly reduced exercise performance in young healthy men and that the threshold of this effect was approximately 3 to 5 percent.

Drinkwater[22] exposed healthy non-smokers to 50 ppm CO and found a significant decrement in the length of time they were able to continue on the treadmill. These data support similar observations reported by Ekblom and Huot[23], and Chevalier[24], et al, and Anderson[25].

There are studies on the effects of other pollutants on cardiovascular function. Smith[26], in a study for the Federal Highway Administration, did not find any change in exercise performance and oxygen consumption measurements in healthy, non-smoking male subjects after the administration of 0.15 or 0.30 ppm of ozone for one hour. This same result is reported by Folinsbee, et al[27], in a study of exercise response following ozone exposure of 0.37, 0.50, or 0.75 ppm for two hours. Studies by Drinkwater on a combination of CO and PAN also produced no noticeable effects on responses to maximal exercise.

(2) Discussion of Hypothesis 4

To test this hypothesis, an engineering analysis-variable profile method was performed, arraying values of the total elapsed treadmill time (TET) for the baseline testing, the mean of the eight runs, and the percent change (TET mean to TET base).

The value for baseline peak heart rate divided by the maximum age predicted heart rate (MAPHR) was compared to the mean eight run peak heart rate divided by the MAPHR, and it was determined that all subjects were performing at their peak capacity. These values are illustrated in Table 13 on the following page.

Four step-wise multiple regressions were then run using change in total elapsed time (TET) as the dependent variable and temperature, relative humidity, CO, ozone, total soluble sulfates, and total soluble nitrates as the independent variables, based on the partitioning attributes of 30-minute bicycle trip, 30-minute motorist trip, 60-minute bicycle trip, and 60-minute motorist trip.

The predictive power of each of these regression equations was assessed by testing the hypothesis that change in TET is independent of CO_C, O_3, TSN, TSS, T, and RH. This was accomplished by using the F test to determine whether or not the coefficient of multiple determination (R^2) is equal to zero and whether or not all of the regression coefficients are equal to zero.

Table 14 on page 83 presents the results of this test for each regression equation. In all cases, the value of F indicates that at the 95 percent level of significance, the hypothesis was proved that $R^2 = 0$ and that all regression coefficients = 0. Therefore, the hypothesis that oxygen transport capacity (as measured by exercise duration) is degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone, and when controlling for the effects of temperature and relative humidity, was not proved.

TABLE 13

Descriptive Data Relative to Exercise Performance

	SUBJECT[a]									Total
	1	2	4	5	6	7	8	9	10	
Baseline (sec.)	775	1,058	728	923	900	840	921	762	940	872
8-Run Mean (sec.)	796.5	1,053.4	738.8	796.0	838.3	843.5	928.5	776.5	938.25	856
8-Run Range (sec.)	755 - 825	997 - 1,100	715 - 761	748 - 843	797- 900	720 - 925	890 - 945	760 - 822	900 - 975	715 - 1,100
% Change M/B[b]	+2.77	-.44	+1.48	-13.76	-6.86	+.42	+.81	+1.90	-.19	-1.84
Baseline Peak/ MAPHR	.94	.96	.98	.99	1.0	1.0	.94	.92	.96	---
8-Run Peak/ MAPHR	.93	.97	.98	.96	.94	.98	.90	.92	.98	---

(a) Subject B-3 data omitted.
(b) M = mean; B = baseline.

TABLE 14

Statistics From the Multiple Regression Analyses for Exercise Duration

VARIABLE								
Dependent	Independent	P. A.[b]	No. of Cases	F	F(.95)[c]	R^2	Beta	D. F.[d]
Change in[a] TET	Temp.	30	36	0.76	2.91	.07	.10	3/32
	Humidity			0.59	2.68	.07	.09	4/31
	CO			1.05	3.29	.06	.23	2/33
	Ozone			1.12	4.13	.03	.18	1/34
Change in TET	Temp.	60	36	----[e]	---	---	---	----
	Humidity			1.07	4.13	.03	.17	1/34
	Ozone			0.43	2.91	.04	-.05	3/32
	CO			0.62	3.29	.04	.08	2/33
Change in TET	Temp.	M	24	1.22	3.47	.10	-.14	2/21
	Humidity			0.66	2.90	.12	-.06	4/19
	Ozone			0.90	3.10	.12	.14	3/20
	CO			2.05	4.30	.08	-.29	1/22
Change in TET	Temp.	B	48	0.24	3.21	.01	.15	2/45
	Humidity			0.24	2.82	.02	.08	3/44
	Ozone			0.32	4.06	.01	.08	1/46
	CO			----	---	---	---	----
Change in TET	Temp.	--	9	0.59	5.41	.26	-.37	3/5
	Humidity			1.20	5.59	.15	.38	1/7
	Ozone			0.89	5.14	.23	.32	2/6
	CO			0.36	6.39	.26	.09	4/4
	Sulfates			----	---	---	---	---
Change in TET	Temp.	--	27	2.36	3.40	.16	-.25	2/24
	Humidity			1.58	3.03	.17	-.08	3/23
	Ozone			0.88	2.68	.17	-.04	5/21
	CO			1.15	2.82	.17	-.05	4/22
	Nitrates			2.80	4.24	.10	.32	1/25

(a) Percent change from baseline level
(b) Partitioning attribute
(c) Value of F required to prove hypothesis at 95 percent level of significance
(d) Sum/residuals
(e) Dashes indicate lack of significant data

The mean percentage change in TET from baseline for bicyclists and motorists was then arrayed by type of route and for the sum of all routes. It was observed that in all cases the mean performance of the bicyclists decreased while the mean performance of the motorists increased (Table 15). The hypothesis was made that the mean percentage change in TET from baseline for bicyclists is equal to the mean percentage change in TET from baseline for motorists and was tested using Student's t test.

Table 15 below presents the results of the test for each case.

TABLE 15

Percentage Changes in Total Elapsed Time From Baseline

Partitioning Category	Number of Cases	Mean Percentage Change and Standard Deviation		t	t(.95)[a]
All Bicyclists, Route W	12	-1.46	±7.62		
All Motorists, Route W	6	+1.89	±3.26	0.92	1.75
All Bicyclists, Route X	12	-2.61	±6.58		
All Motorists, Route X	6	+0.57	±2.19	1.00	1.75
All Bicyclists, Route Y	12	-5.57	±6.68		
All Motorists, Route Y	6	+0.46	±2.41	4.30	1.75
All Bicyclists, Route Z	12	-1.16	±7.28		
All Bicyclists, Route Z	6	+0.45	±2.41	1.10	1.75
All Bicyclists	48	-2.70	±7.04		
All Motorists	24	+0.84	±2.47	2.40	1.67

(a) Value of t required to prove Hypothesis 4 at the 95 percent level of significance

In the case of routes W, X, and Z, the hypothesis was proved that the mean percentage change is equal. In the case of Route Y and the case of all routes combined, the value of t indicates that the hypothesis was not proved (that the mean percentage change is equal).

Further examination of the raw data indicated that one individual's performance was vastly different from the performance by other participants in the study. Often, when a statistical population is small ($n < 15$), individual cases may disproportionately skew results. Such data "outliers" may be detected by use of the standard deviation measure to gauge their relative remoteness from the group norm. Specifically, Subject B-5 is noted to have an overall mean percentage change in TET of -13.76, which is nearly two standard deviations removed from the group (bicyclists') mean. A second table replicating the form of the preceding one but omitting the data of B-5 is presented on the following page as Table 16. Using this reduced set of data, the differences between bicyclists and motorists in terms of percent changes in TET from baseline become negligible.

The revised results of this study (following exclusion of B-5 data) do not reveal a significant decrement in performance on the maximal multi-stage treadmill test by the bicyclists or motorists. Previously cited studies finding performance decrements measured CO levels starting at 50 ppm or higher (in contrast to CO levels of 9.3 ppm $\pm$ 4.2 for all motorists and 8.3 ppm $\pm$ 4.6 for all bicyclists participating in this study), and COHb levels between

TABLE 16

Percentage Changes in Total Elapsed Time From Baseline[a]

Partitioning Category	Number of Cases	Mean Percentage Change and Standard Deviation		t	t(.95)[b]
Bicyclists, Route W	10	+0.86	(±5.93)	-0.39	-1.76
Motorists, Route W	6	+1.89	(±3.26)		
Bicyclists, Route X	10	-0.45	(±4.65)	-0.50	-1.76
Motorists, Route X	6	+0.57	(±2.19)		
Bicyclists, Route Y	10	-3.73	(±5.63)	-1.60	-1.76
Motorists, Route Y	6	+0.46	(±2.41)		
Bicyclists, Route Z	10	+1.38	(±4.03)	0.49	+1.76
Motorists, Route Z	6	+0.45	(±2.41)		
Bicyclists, All Routes	40	-0.49	(±5.31)	-1.20	-1.67
Motorists, All Routes	24	+0.84	(±2.47)		

(a) Subject B-5 data omitted
(b) Value of t required to prove Hypothesis 4 at the 95 percent level of significance

3.95 percent and 20 percent (while levels of post-exposure COHb in this study averaged 1.7 percent for all bicyclists and 2.1 percent for all motorists).

No significant relationships could be observed between ozone and total soluble sulfates and nitrates, and change in total elapsed treadmill time.

To assess the effects of thermal stress, total elapsed time was compared to changes in body weight, temperature,

and humidity without any significant results. In contrast, Drinkwater[22] concluded that heat stress, more than pollutants, appeared to reduce work capacity.

There were no significant differences found in resting or exercise mean systolic blood pressure levels, diastolic blood pressure and heart rate, confirming the findings of Aronow and Cassidy[21].

Examination of EKG changes occurring during the maximal multi-stage exercise testing revealed the following:

- One subject experienced non-specific ST segment changes not severe enough to interfere with eligibility or stop the testing.
- No subjects experienced significant arrhythmias.
- One subject experienced minimal atrio-ventricular conduction delay before and after exercise testing not severe enough to interfere with eligibility or performance of maximal exercise.

Reasons for terminating exercise in the maximal multi-stage exercise testing were:

- Symptoms
- Significant EKG change (arrhythmia or ST displacement)
- Systolic blood pressure > 225 mm/Hg
- Diastolic blood pressure > resting B.P. by 20 mm/Hg.

Because of the careful selection of healthy subjects, the only stopping category utilized in this study was symptoms, the most frequent being generalized fatigue.

(3) Findings of Hypothesis 4

The findings of Hypothesis 4 were:

- Oxygen transport capacity measured by exercise duration during maximal multi-stage exercise testing was not degraded from baseline values among the bicyclists and motorists exposed to the pollution levels and thermal stress encountered in this study.

It was also observed that:

- Exercise function as measured by maximal multi-stage exercise testing was generally consistent over time for the study subjects.
- Study subjects did not experience any untoward cardiovascular symptoms during maximal multi-stage exercise testing while participating in this project.

2.5 Hypothesis 5

Hypothesis 5 is defined as follows:

- The results of pulmonary screening tests are degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.

This hypothesis was not proved in this study.

(1) Background of Hypothesis 5

Studies by Hazucha[28], et al, 1973, showed reduced pulmonary function in healthy smokers and non-smokers after exposure to ozone at 0.37 ppm and higher for two hours. Hackney[29] used various tests of ventilatory function to show that healthy male college students experienced no effect of sulfur dioxide at 0.37 ppm, a 10 percent decline in function with ozone at 0.37 ppm, and a 20-40 percent decline in function with a combination of sulfur dioxide at 0.37 ppm and ozone at 0.37 ppm. Smith[26] (1976) studied threshold levels of ozone (0.15 and 0.30 ppm) required to induce deterioration change in lung function and aerobic exercise performance and did not find significant pulmonary function changes at low ventilation volumes. Exposure to 0.15 and 0.30 ppm ozone at a difficult work load for one hour, however, resulted in marked symptoms of discomfort and impaired lung function.

(2) Discussion of Hypothesis 5

In order to test this hypothesis, the values of the dependent variables, percent of predicted forced vital capacity, the percent of forced expiratory volume at one second, percent predicted peak flow, forced expiratory flow at 50 percent of forced vital capacity, and the percent predicted forced expiratory flow at 25-75 percent of total forced expiratory volume, were arrayed by partitioning attributes and by the independent variables of temperature, relative humidity, carbon monoxide, ozone, total soluble nitrates, and total soluble sulfates.

A series of step-wise multiple linear regressions were then run for each of the five dependent variables against the independent variables of carbon monoxide (CO_C), ozone (O_3), total soluble nitrates (TSN), total soluble sulfates (TSS), temperature (T), and relative humidity (RH) and partitioned by mode of transportation and length of trip.

The predictive power of each of these regression equations was assessed by testing the hypothesis that each of the five pulmonary function variables is independent of CO_C, O_3, TSN, TSS, T, and RH. This was accomplished by using the F test to determine whether or not the coefficient of multiple determination (R^2) is equal to zero and whether or not <u>all</u> of the regression coefficients are equal to zero.

Table 17 on the following pages presents the results of this test for each regression equation. In all cases, the value of F indicates that at the 95 percent level of significance, the hypothesis that $R^2 = 0$ was proved and all regression coefficients = 0. (In a few cases, a significant relationship was found between temperature and changes in pulmonary functions and in one case, a significant relationship was found between ozone and changes in pulmonary functions. However, when additional independent variables were introduced into the step-wise multiple regressions, the significant relationships were no longer observed.) Therefore, the hypothesis that the results of pulmonary screening tests are degraded from a set of baseline results when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone, when controlling for the effects of temperature and relative humidity, was not proved.

TABLE 17

Statistics From the Multiple Regression Analysis for Pulmonary Functions

VARIABLE Dependent	VARIABLE Independent	P.A.[b]	No. of Cases	F	F (.95)[c]	R^2	Beta	D.F.[d]
(a) Change in % of Pred. FVC	Temp.	30	39	0.82	4.12	.02	.15	1/36
	Humidity			0.40	2.90	.03	-.08	3/34
	CO			0.57	3.37	.03	-.10	2/35
	Ozone			0.32	2.67	.04	.07	4/33
Change in % of Pred. FVC	Temp.	60	39	0.72	4.05	.02	.14	1/37
	Humidity			0.41	3.27	.02	.08	2/36
	CO			0.29	2.89	.02	-.04	3/35
	Ozone			0.23	2.66	.02	.05	4/34
Change in % of Pred. FVC	Temp.	M	24	0.12	3.47	.01	-.06	2/21
	Humidity			0.08	2.90	.02	.05	4/19
	CO			0.19	4.30	.01	-.09	1/22
	Ozone			0.09	3.10	.01	.05	3/20
Change in % of Pred. FVC	Temp.	B	53	3.97	4.04	.07	.27	1/51
	Humidity			----[e]	----	---	----	----
	CO			1.98	3.19	.07	-.03	2/50
	Ozone			1.32	2.81	.07	.04	3/49
Change in % Pred. FEV_1	Temp.	30	38	1.34	4.13	.04	.19	1/34
	Humidity			0.53	2.91	.05	.10	3/32
	CO			0.70	3.29	.04	-.06	2/33
	Ozone			----	----	---	----	----
Change in % Pred. FEV_1	Temp.	60	35	0.41	2.92	.04	.07	3/31
	Humidity			0.57	3.30	.03	.09	2/32
	CO			0.31	2.89	.04	-.04	4/30
	Ozone			0.89	4.14	.03	.16	1/33
Change in % Pred. FEV_1	Temp.	M	24	0.71	4.30	.03	-.18	1/22
	Humidity			0.56	3.47	.05	.14	2/21
	CO			0.42	3.10	.06	-.10	3/20
	Ozone			0.31	2.90	.08	.06	4/19
Change in % of Pred. FEV_1	Temp.	B	53	5.78	4.04	.10	.32	1/51
	Humidity			2.00	2.58	.14	-.02	4/48
	CO			2.71	2.81	.14	-.04	3/49
	Ozone			4.09	3.19	.14	.20	2/50
Change in % of Pred. P. F.	Temp.	30	36	5.33	4.13	.14	.37	1/34
	Humidity			2.88	3.29	.14	.07	2/33
	CO			----	----	---	----	----
	Ozone			1.80	2.91	.14	-.08	3/32
Change in % of Pred. P. F.	Temp.	60	35	0.82	4.14	.02	.15	1/33
	Humidity			0.45	2.92	.04	.09	3/31
	CO			0.58	3.30	.03	-.10	2/32
	Ozone			----	----	---	----	----
Change in % of Pred. P. F.	Temp.	M	24	0.84	3.10	.09	.15	3/20
	Humidity			0.68	4.30	.03	.17	1/22
	CO			0.74	3.47	.06	-.20	2/21
	Ozone			----	----	---	----	----
Change in % of Pred. P. F.	Temp.	B	47	5.87	4.08	.12	.34	1/45
	Humidity			1.42	2.60	.12	.02	4/42
	CO			1.93	2.82	.12	-.03	3/43
	Ozone			2.94	3.21	.12	-.05	2/44
Change in % of Pred. $FEF_{25-75\%}$	Temp.	30	38	2.04	3.29	.11	-.11	2/33
	Humidity			3.72	4.13	.10	.31	1/34
	CO			1.37	2.91	.11	-.07	3/32
	Ozone			1.00	2.68	.11	.03	4/31
Change in % of Pred. $FEF_{25-75\%}$	Temp.	60	35	0.27	2.92	.02	-.05	3/31
	Humidity			0.20	2.89	.03	.03	4/30
	CO			0.76	4.14	.02	.15	1/33
	Ozone			0.39	3.30	.02	.04	2/32
Change in % of Pred. $FEF_{25-75\%}$	Temp.	M	24	1.60	3.47	.13	-.22	2/21
	Humidity			2.01	4.30	.08	.29	1/22
	CO			1.12	3.10	.14	-.11	3/20
	Ozone			0.82	2.90	.15	-.07	4/19
Change in % of Pred. $FEF_{25-75\%}$	Temp.	B	47	----	----	---	----	----
	Humidity			1.20	2.82	.08	.10	3/43
	CO			1.63	3.21	.07	.18	2/44
	Ozone			2.04	4.06	.04	.21	1/45

(a) Percent change from baseline level
(b) Partitioning attribute
(c) Value of F required to prove hypothesis at 95 percent level of significance
(d) Degrees of freedom, sum/residuals
(e) Hyphens denote lack of significant data

VARIABLE Dependent	Independent	No. of Cases	F	F (.95) (b)	R^2	Beta	D. F. (c)
(a) Change in % of Pred. FVC	Temp.	8	---- (d)	----	---	----	----
	Humidity		0.45	5.79	.15	-0.29	2/5
	CO		0.50	5.99	.08	0.28	1/6
	Ozone		0.30	6.59	.18	-0.36	3/4
	Sulfate		0.19	9.12	.20	0.33	4/3
Change in % of Pred. $FEF_{25-75\%}$	Temp.	8	4.29	5.99	.42	0.64	1/6
	Humidity		----	----	---	----	----
	CO		3.83	9.12	.84	0.07	4/3
	Ozone		9.50	5.79	.79	-1.40	2/5
	Sulfate		6.76	6.59	.83	-0.21	3/4
Change in % of Pred. P. F.	Temp.	7	0.83	6.94	.29	-0.65	2/4
	Humidity		2.96	19.20	.86	0.08	4/2
	CO		----	----	---	----	----
	Ozone		0.95	6.61	.16	0.40	1/5
	Sulfate		5.78	9.28	.85	-1.80	3/3
Change in % of Pred. FEF_{50}	Temp.	8	5.21	5.99	.46	0.68	1/6
	Humidity		----	----	---	----	----
	CO		1.76	6.59	.57	-0.21	3/4
	Ozone		2.79	5.79	.53	-0.59	2/5
	Sulfate		1.33	9.12	.64	-0.52	4/3
Change in % of Pred. FVC	Temp.	30	1.65	4.19	.06	0.23	1/28
	Humidity		1.06	3.38	.07	0.13	2/27
	CO		----	----	---	----	----
	Ozone		0.51	2.76	.08	0.04	4/25
	Nitrate		0.70	2.98	.07	0.04	3/26
Change in % of Pred. $FEF_{25-75\%}$	Temp.	19	0.85	3.11	.19	-0.07	4/14
	Humidity		0.63	2.96	.20	0.03	5/13
	CO		2.54	4.45	.13	0.36	1/17
	Ozone		1.82	3.63	.18	0.24	2/16
	Nitrate		1.18	3.29	.19	0.08	3/15
Change in % of Pred. P. F.	Temp.	20	0.66	3.59	.07	0.15	2/17
	Humidity		0.60	3.06	.14	0.14	4/15
	CO		0.47	2.96	.14	0.09	5/14
	Ozone		0.73	3.24	.12	-0.26	3/16
	Nitrate		0.93	4.41	.05	0.22	1/18
Change in FEF_{50}	Temp.	30	0.84	2.98	.09	-0.05	3/26
	Humidity		1.92	4.19	.06	0.25	1/28
	CO		0.62	2.76	.09	-0.05	4/25
	Ozone		----	----	---	----	----
	Nitrate		1.26	3.38	.08	0.15	2/27

(a) Change relative to baseline value
(b) Value of F required to prove hypothesis at 95 percent level of significance
(c) Degrees of freedom, sum/residuals
(d) Hyphens denote lack of significant data

As a by-product of the step-wise multiple regression, a high degree of correlation among the pulmonary function variables was noted (as expected). Table 18 below presents a correlation matrix showing the degree of these interrelationships.

TABLE 18

Pulmonary Variables: Intercorrelation Matrix

	% of Pred. FVC [a]	% of Pred. FEV_1 [b]	% of Pred. PF [c]	FEF_{50} [d]	% of Pred. $FEF_{25-75\%}$ [e]
% Pred. FVC	1.00	.775	-.603	-.462	-.395
% Pred. FEV_1	.775	1.00	-.659	.096	.254
% of Pred. PF	-.603	-.659	1.00	.127	.020
FEF_{50}	-.462	.096	.127	1.00	.869
% of Pred. $FEF_{25-75\%}$	-.395	.254	.020	.869	1.00

(a) Percent predicted forced vital capacity
(b) Percent predicted forced expiratory volume at one second
(c) Percent predicted peak flow
(d) Forced expiratory flow at 50 percent of forced vital capacity
(e) Percent predicted forced expiratory flow at 25-75 percent of total forced expiratory volume

As there is a wide normal variation in pulmonary function tests, especially for forced expiratory flow rates, (apart from variations due to age, height, or sex) a 20 percent decrease from the best of two preliminary screenings was established by Dr. Jerome Putnam, Director of the Pulmonary Laboratory, as a medically significant change for the purpose of this study. The review of the individual raw data

indicated that one motorist control (M-2) experienced a level of 18 percent decrease on two occasions on two of the pulmonary function tests which are effort-independent. These were Forced Expiratory Flow ($FEF_{25-75\%}$) which is the average rate of flow during the middle half of the forced expiratory volume, and Forced Expiratory Flow at 50 percent of Forced Vital Capacity (FEF_{50}) which is an instantaneous flow measurement of the relationship of the forced expiratory flow to the forced vital capacity. Results of these tests are used to reflect the properties of the lungs and small airways in contrast to Forced Vital Capacity (FVC) and Forced Expiratory Volume at one second (FEV_1) which are effort-dependent phenomena with results used to indicate airflow in the larger airways.

These minimally abnormal results could not be related to any particular levels in measured pollutants, temperature, or relative humidity, nor was there any relationship to the pulmonary values of Subject B-2 who travelled the same routes at the same time.

This result could only be related to the fact that M-2 stopped smoking just prior to the beginning of the study. There is a need for further research with a population which may be more susceptible to the levels of pollution encountered in the study than the ten healthy subjects who were studied.

(3) Findings of Hypothesis 5

A series of pulmonary function tests was not significantly degraded from a set of baseline values among bicyclists

and motorists exposed to the pollutant levels and thermal stress encountered in this study.

2.6 Hypothesis 6

Hypothesis 6 is defined as follows:

- A change in physical signs and symptoms occurs when bicyclists and motorists are exposed to carbon monoxide, total soluble sulfates, total soluble nitrates, and ozone typically encountered in an urban environment.

This hypothesis was proved for changes in fatigue and eye irritation related to exposure to nitrates for bicyclists (for the duration and level of exposure encountered in this study) but was not proved in all other cases.

(1) Background of Hypothesis 6

Changes in certain physical signs and symptoms have been attributed to a number of different pollutants.

Richardson and Middleton[30] found a highly significant correlation between levels of eye irritation and oxidant concentration in the Los Angeles area. Hackney et al [31] found significant relationships between symptoms of cough, substernal pain, wheezing, and malaise and ozone exposures of 0.5 and 0.37 ppm among individuals with pre-existing pulmonary hyper-reactivity, and no or minimal effects among subjects without this history. In this latter group of subjects, addition of NO_2 and CO also did not produce any detectable effects.

Irritation of the eyes and respiratory tract has been attributed to sulfates, nitrates, and photochemical oxidants, while increased cough and chest discomfort have been related to total suspended particulate levels[32].

(2) Discussion of Hypothesis 6

To test this hypothesis, an engineering analysis was performed on the following signs and symptoms: cough, wheeze, sputum, substernal pain, dyspnea, fatigue, headache, sore throat, laryngeal irritation, nasal discharge, and eye irritation. Any negative change from beginning to end of trip received the value 1 and no change received the value of zero as displayed in Table 19 below.

TABLE 19

Symptom Change Analysis

	# of Observations:		Normalized Values:[a]	
Symptom	Bicyclists	Motorists	Bicyclists	Motorists
Cough	5	0	0.7	0.0
Fatigue	11	3	2.6	1.0
Headache	6	2	0.8	0.7
Sore Throat	28	0	4.0	0.0
Laryn. Irr.	25	6	3.6	2.0
Eye Irr.	30	3	4.1	1.0
Other	16	2	2.3	0.7
TOTAL	127	16	18.0	6.0

(a) Occurrences per subject

From the normalized values of number of occurrences of symptom change, it is readily apparent that bicyclists experienced more instances of fatigue, sore throat, laryngeal irritation and eye irritation than the motorists. The fatigue can be attributed to the differences in activity levels between the bicyclists and motorists. The symptom of "sore throat" was used by the bicyclists to describe dry throat which is the natural sequel to mouth breathing, and was often accompanied by actual laryngeal irritation. The eye irritation experienced by the bicyclist results from unprotected exposure of the eyes, in contrast to the motorist who is protected by the windshield. Many of the bicyclists complained of actual particles getting in their eyes as they rode.

Investigation of the possibility that longer exposure times would bring on more symptom changes showed that for both modes of transportation an approximately equal number of negative symptom changes was detected for both durations. Table 20 below illustrates this frequency.

TABLE 20

Frequency of Symptom Change, Percent of All Cases

Length of Trip	Bicyclists	Motorists
30-minute	46.2	46.8
60-minute	53.8	53.2
TOTAL	100.0	100.0

Three of the symptoms that occurred most frequently when examined were: laryngeal irritation and eye irritation, observed objectively by trained health professionals; and fatigue, which was reported by the subjects. (Sore throat was also a frequently reported symptom, but was often used to describe the symptom of <u>dry throat</u> as the result of mouth breathing. Therefore this subjectively reported symptom was not used in the detailed analysis that follows.)

In order to examine the relationship between ozone and changes in symptoms, the values for ozone levels were divided into three categories: 0 to 49 parts per billion (ppb), 50 to 99 ppb, and 100 ppb or greater. Also, the values for changes in symptoms were divided into two categories: detected changes and non-detected changes. A two-way classification table was then constructed for each of the following cases:

- Fatigue vs. ozone (bicyclists)
- Laryngeal irritation vs. ozone (bicyclists)
- Eye irritation vs. ozone (bicyclists)
- Fatigue vs. ozone (motorists)
- Laryngeal irritation vs. ozone (motorists)
- Eye irritation vs. ozone (motorists).

The χ^2 test was then used to test the hypothesis that changes in symptoms are independent of ozone levels.

Table 21 on the following page presents the results of this test for each two-way classification. In all cases, the value of χ^2 indicates that at the 95 percent level of

TABLE 21

Detection[a] Frequencies:
Symptom Occurrence vs. Ozone Concentration

Symptoms	Ozone, ppb 0 - 49	Ozone, ppb 50 - 99	Ozone, ppb 100+	χ^2	$\chi^2(.95)$[b]	D.F.[c]
BICYCLISTS						
Fatigue						
Detections	10	5	4	4.16	5.99	2
Non-Detections	10	19	6			
Laryngeal Irr.						
Detections	8	13	4	1.10	5.99	2
Non-Detections	12	11	6			
Eye Irritation						
Detections	10	14	6	0.41	5.99	2
Non-Detections	10	10	4			
MOTORISTS						
Fatigue						
Detections	0	2	1	2.12	5.99	2
Non-Detections	9	9	3			
Laryngeal Irr.						
Detections	2	3	1	0.04	5.99	2
Non-Detections	7	8	3			
Eye Irritation						
Detections	1	1	1	0.71	5.99	2
Non-Detections	8	10	3			

(a) Changes in symptom degree>0 (post-pre)
(b) Value of χ^2 to prove Hypothesis 6 at the 95 percent level of significance
(c) D. F. = degree of freedom

significance, the hypothesis that changes in symptoms are independent of ozone levels was proved. Therefore, the hypothesis that a change in physical signs and symptoms occurs when bicyclists and motorists are exposed to ozone (for the duration and level of exposure encountered in this study) was not proved.

In order to examine the relationship between nitrates and changes in symptoms, the values for nitrate levels were divided into two categories: detected levels and non-detected levels. The values for changes in symptoms were divided into two categories: detected changes and non-detected changes. A two-way classification table was then constructed for each of the following cases:

- Fatigue vs. nitrates (bicyclists)
- Laryngeal irritation vs. nitrates (bicyclists)
- Eye irritation vs. nitrates (bicyclists)
- Fatigue vs. nitrates (motorists)
- Laryngeal irritation vs. nitrates (motorists)
- Eye irritation vs. nitrates (motorists).

The χ^2 test was then used to test the hypothesis that changes in symptoms are independent of nitrate levels.

Table 22 on the following page presents the results of this test for each two-way classification. In the following four cases, the value of χ^2 indicates that at the 95 percent level of significance, the hypothesis that changes in symptoms are independent of nitrate levels is proved:

TABLE 22

Detection Frequencies:[a]

Symptom Occurrence vs. Nitrate Levels

Symptoms	Detected Nitrate Levels	Non-Detected Nitrate Levels	χ^2	$\chi^2 (.95)$[b]	D. F.[c]
BICYCLISTS					
Fatigue					
Detections	5	21	4.99	3.84	1
Non-Detections	14	13			
Laryngeal Irr.					
Detections	9	21	3.28	3.84	1
Non-Detections	13	9			
Eye Irritation					
Detections	11	19	5.83	3.84	1
Non-Detections	17	6			
MOTORISTS					
Fatigue					
Detections	1	2	0.00	3.84	1
Non-Detections	10	10			
Laryngeal Irr.					
Detections	3	3	0.00	3.84	1
Non-Detections	10	10			
Eye Irritation					
Detections	1	1	0.00	3.84	1
Non-Detections	9	9			

(a) Changes in symptom degree>0 (post-pre)

(b) Value of χ^2 required to prove Hypothesis 6 at the 95 percent level of significance

(c) D. F. = degree of freedom

- Fatigue vs. nitrates (motorists)
- Laryngeal irritation vs. nitrates (motorists)
- Laryngeal irritation vs. nitrates (bicyclists)
- Eye irritation vs. nitrates (motorists).

In the following two cases, the values of χ^2 indicates that at the 95 percent level of significance, the hypothesis that changes in symptoms are independent of nitrate levels is not proved:

- Fatigue vs. nitrates (bicyclists)
- Eye irritation vs. nitrates (bicyclists).

Therefore, the hypothesis that a change in fatigue, laryngeal irritation, and eye irritation occurs when motorists are exposed to nitrates (for the duration and level of exposure encountered in this study) is not proved; the hypothesis that a change in laryngeal irritation occurs when bicyclists are exposed to nitrates (for the duration and level of exposure encountered in this study) is not proved; and the hypothesis that a change in fatigue and eye irritation occurs when bicyclists are exposed to nitrates (for the duration and level of exposure encountered in this study) is proved.

No significant statistical relationship could be found between ozone and nitrates and three of the symptoms that occurred most frequently, disaggregated by mode of transportation.

Due to the low number (1) of observations of CO_C in excess of the National Secondary Health Standard (20 ppm), no attempt was made to statistically link carbon monoxide concentration with symptom change.

Likewise, due to the low number of sulfate detections (9), no attempt was made to statistically relate sulfate concentrations with symptom change.

Caution must be used in interpreting this section on the changes in signs and symptoms. Although the same person always performed the pre- and post-exposure examination of signs and symptoms, these are not blind studies, and the examiner was well aware of the status of the subject (i.e., pre- or post-exposure).

Many of the symptom changes that occurred were transitory in nature (disappearing by the end of the testing period) and subjects reported all symptoms disappeared by the next morning. Symptoms of wheezing, substernal pain and dyspnea were never reported during the testing period.

It is important to recognize the individual biologic variations in the absorption and metabolism of chemicals and random variations in sensitivity tolerance developed through long residence in a polluted area, when interpreting these results.

(3) <u>Findings of Hypothesis 6</u>

The findings of Hypothesis 6 were:

- Bicyclists participating in this study experienced more occurrences of fatigue, sore throat, laryngeal irritation and eye irritation than the motorists participating in this study.

- No relationship was found between number of occurrences of symptom change and levels of measured pollutants encountered by the motorists in this study.

- A relationship was found between occurrences of fatigue and eye irritation and the concentration of nitrates encountered by the bicyclists in this study.

- Symptoms of wheezing, dyspnea, and substernal pain were never experienced by bicyclists and motorists exposed to the pollutant levels and thermal stress encountered in this study.

It was also observed that:

- Most symptom change encountered by the bicyclists and motorists participating in the study was transitory in nature and disappeared readily.

- All of the bicyclists participating in this study stated that the hazards to bicyclists from traffic outweighed the hazards to bicyclists from pollution.

IV. CONCLUSIONS

1. SUMMARY OF FINDINGS AND OBSERVATIONS

The findings and observations of this study are:

- Based upon this study of ten healthy male subjects, no major adverse short-term health effects were noted while bicycling or driving in levels of pollution and thermal stress encountered during the testing period.

- CO levels monitored at the permanent air monitoring station utilized in this study were consistently lower than the actual CO levels experienced by the bicyclists and motorists participating in this study.

- CO levels experienced by bicyclists were approximately the same as those experienced by their motorist controls traveling the same routes at the same times while participating in this study.

- Actual CO levels experienced by bicyclists and motorists participating in this study were not a valid predictor of the actual levels of total soluble sulfates and total soluble nitrates experienced by these same subjects.

- The average venous carboxyhemoglobin post-exposure level was greater than the average venous carboxyhemoglobin pre-exposure level for bicyclists and motorists for some of the partitioning categories while participating in this study.

- COHb levels experienced by the bicyclists and motorists in this study were not related to the levels of CO *in situ* or the length of exposure time encountered in this study.

- COHb levels measured for motorist controls were slightly higher than those encountered in the bicyclists who participated in this study.

- Traffic slow-downs or intersection delays may have more impact on increasing levels of COHb than the low levels of CO encountered by the bicyclists and motorists while traveling the different designated routes of this study.

- Mean COHb post-exposure levels were 2.1 percent for motorists and 1.7 percent for bicyclists for the entire set of partitioning attributes. These were not significantly higher than pre-exposure levels and were well below the daily levels of 4-6 percent encountered in smokers who smoke 1-2 packs of cigarettes a day.

- Levels of measured CO in this study never exceeded the National Primary Standard (one hour) for ambient air (35 ppm).

- Levels of ozone measured in this study had a wide range of values and frequently exceeded the National Primary Standard for ambient air (80 ppb, one-hour) on 30 of the test runs (38 percent).

- Oxygen transport capacity measured by exercise duration during maximal multi-stage exercise testing was not degraded from baseline values among the bicyclists and motorists exposed to the pollution levels and thermal stress encountered in this study.

- Exercise function as measured by maximal multi-stage exercise testing was generally consistent over time for the study subjects.

- Study subjects did not experience any untoward cardiovascular symptoms during maximal multi-stage exercise testing while participating in this project.

- A series of pulmonary function tests was not significantly degraded from a set of baseline values among bicyclists and motorists exposed to the pollutant levels and thermal stress encountered in this study.

- Bicyclists participating in this study experienced more occurrences of fatigue, sore throat, laryngeal irritation and eye irritation than the motorists participating in this study.

- No relationship was found between number of occurrences of symptom change and levels of measured pollutants encountered in this study.

- A relationship was found between occurrences of fatigue and eye irritation and the concentration of nitrates encountered by the bicyclists in this study.

- Symptoms of wheezing, dyspnea, and substernal pain were never experienced by bicyclists and motorists exposed to the pollutant levels and thermal stress encountered in this study.

- Most symptom changes encountered by the bicyclists and motorists participating in the study were transitory in nature and disappeared readily.

- All of the bicyclists participating in this study stated that the hazards to bicyclists from traffic outweighed the hazards to bicyclists from pollution.

2. RECOMMENDATIONS FOR FURTHER STUDY

2.1 Recommendation One

As bicycle paths located away from automotive traffic streams continue to be constructed, questions remain as to the importance of locating the routes away from the main traffic stream. Studies have shown that levels of metals (such as lead), sulfur oxides, nitrogen oxides, and carbon monoxide will be diminished at locations away from roads. Everett[12] found that bicyclists and joggers are much less likely to perceive ill effects of pollution when separated by 30 to 50 feet from traffic. However, the pollutant generally recognized as the most prevalent and the most hazardous (at its typical concentrations) is ozone[26], which is regionally variable and can be found in even smaller concentrations within the traffic stream than apart from it at certain times of the day.

A study to analyze this problem would involve a paired (yoked) set of runs of bicyclists—one set of subjects within a traffic stream,

the other on a nearby bike path, at least several yards apart. A sub-study could measure the effect of barriers (such as trees) between the roadways and bike paths. These data would be evaluated in relation to the safety of each type of route, type and amount of pollutant collected on each route, and any health effects encountered while riding each route (i. e., change in pulmonary function, change in cardiovascular function, symptom change, etc.).

2.2 Recommendation Two

Although none of the subjects exceeded the 20 percent level of significant pulmonary degradation, it is noted that the one subject approaching this criterion was a former smoker (and the one who had most recently stopped smoking). This result (as well as studies by many researchers such as Hackney, et al [29,31], Hazucha[28] and others) highlights the relative vulnerability of smokers and individuals with chronic respiratory ailments to levels of pollution (especially ozone and particulates) that do not affect healthy non-smokers. It is recommended that a study similar to this be conducted to determine the magnitude of impact of pollution upon the health of smokers and other susceptible types of individuals.

A long-term study (six months to two years) of regularly bicycling smokers and persons with respiratory ailments would be of more medical significance than a short-term study. Cities where summertime levels of ozone accumulation approach and exceed levels found to bring on respiratory stress in these individuals (e.g., New York, Baltimore) would be particularly appropriate locations for such a study.

2.3 Recommendation Three

An important concern not addressed by this study is the cumulative health effects of long-term bicycling in an urban environment. Simple, rapid tests (e.g., pulmonary screening) could be performed on a regular basis on commuting bicyclists and motorists, with participants drawn from a cross-section of the bicycle commuting public. This type of study would involve periodic testing of the respiratory health of participants at a central screening location (such as a health clinic). The testing program would be fairly inexpensive on a per person basis and a large number of subjects could be used. Suburban dwellers who do not commute could be used as controls, and different age brackets could also be studied.

2.4 Recommendation Four

A comprehensive safety survey of large cities should be undertaken to understand causes and prevention of bicycling accidents in city traffic. Data obtained from traffic research divisions and police precincts would serve as the study base. A study of a large bicycling community[33], the American League of Wheelmen, and a local group, the Washington Area Bicycling Association, indicates that many cyclists will potentially ride all year round in a variety of climates and during the congested commuting hours. The need for such a precautionary survey before officially advocating increased bicycle commuting is clearly indicated.

Such a survey would correlate the use of safety equipment and severity of injury, pinpoint accident prone areas and outline safe operating procedures. Results could be used to help decide whether to allow bicycling in traffic corridors or to provide specially constructed bicycle routes apart from roadways.

APPENDIX A

RAW DATA GATHERED DURING THE STUDY

This appendix consists of the following exhibits:

- Exhibit 6—Computer Program Used to Array Data
- Exhibit 7—Cardiovascular Data
- Exhibit 8—Symptom Check Lists Data
- Exhibit 9—Pulmonary Function Data
- Exhibit 10—Pollutant Concentration Data
- Exhibit 11—Meteorological Data.

APPENDIX A(2)

EXHIBIT 6

Computer Program Used
to Array Data

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DIMENSION ANAME(10,10),IBLOOD(10,4,2,2),IHEART(10,4,2),IMAPHR(10,2)
DIMENSION IEKG(10,5,2),ISTDP(10,4,2),FITIME(10,2),ORALTE(10,8,2)
DIMENSION PULSE(10,8,2),RESPIR(10,8,2),WEIGHT(10,8,2),COHG(10,8,2)
DIMENSION COUGH(10,8,2),WHEEZE(10,8,2),SPUTUM(10,8,2),SBPAIN(10,8,2)
DIMENSION DYSPNE(10,8,2),FATIG(10,8,2),HEADAC(10,8,2),SORETH(10,8,2)
DIMENSIDN LARYNG(10,8,2),NASAL(10,8,2),EYEIRR(10,8,2),BLOOD(10,8,4,2)
DIMENSION HEART(10,8,4),EKG(10,8,5),STOP(10,8,4),PULMON(10,8,12),PULPRE(10,12,2)
DIMENSION ITIME(10,8),COSITU(10,8),COAMBI(10.8),O3AMBI(10,8)
DIMENSION AMDDE(10,8),ACOMID(10,8),AROUTE(10,8),NTIME(10,8),MAPHR(10,8)
DIMENSION TPAMBI(10,8),NO3SIT(10,8),SO4SIT(10,8)
REAL NO3SIT
INTEGER RUN,REC,COUGH,WHEEZE,SPUTUM,SBPAIN,DYSPNE,FATIG,HEADAC
INTEGER SDRETH,EYEIRR,BLOOD,HEART,EKG,STDP,D3AMBI,TPAMBI
DO 3000 ISUB=1,10
READ(11,7905) NAME,(ANAME(ISUB.J),J=1,10)
7905 FORMAT (I2,3X,10A4)
IF (ISUB.NE.NAME) STOP 1
READ(11.7906) NAME,(((IBLOOD(ISUB,ITEST,J,ITYPE),ITYPE=1,2),J=1,2),ITEST=1,4)
7906 FDRMAT(I2,16I4)
IF (ISUB.NE.NAME) STOP 2
READ(11,7907) NAME,((IHEART(ISUB,ITEST,J),J=1,2),ITEST=1,4),%
(IMAPHR(ISUB,J),J=1,2),((IEKG(ISUB,ITEST,J),J=1,2),ITEST=1,5)
7907 FORMAT (I2,10I4,10I2)
IF (ISUB.NE. NAME) STOP  3
READ(11,7908) NAME,((ISTOP(ISUB,ITEST,J),J=1,2),ITEST=1,4),%
(FITIME(ISUB,J),J=1,2)
7908 FORMAT(I2,8I2,2F6.1)
IF (ISUB.NE.NAME) STOP 4
READ(11,7912) NAME,((PULPRE(ISUB,ITEST,J),J=1,2),ITEST=1,6)
READ(11,7913) NAME,((PULPRE(ISUB,ITEST,J),J=1,2),ITEST=7,12)
7912 FORMAT(I2.12F6.2)
7913 FORMAT(I2,12F6.2)
DO 2000 IRUN=1,8
READ(11,7910) NAME,RUN,REC,AMODE(ISUB,IRUN),ACOMID(ISUB,IRUN),%
AROUTE(ISUB,IRUN),NTIME(ISUB,IRUN),(ORALTE(ISUB,IRUN,J),J=1,2),%
(PULSE(ISUB,IRUN,J),J=1,2),(RESPIR(ISUB,IRUN,J),J=1,2),(WEIGHT%
(ISUB,IRUN,J),J=1,2)
7910 FORMAT(I2,I3,I5,3(1X,A2),I3,8F6.1)
IF (ISUB.NE.NAME) STOP 5
IF (IRUN.NE.RUN) STOP 6
IF (REC.NE.1) STOP 7
READ(11,7915) NAME,RUN,REC,(COHG(ISUB,IRUN,J),J=1,2),%
(COUGH(ISUB,IRUN,J),J=1,2),(WHEEZE(ISUB,IRUN,J),J=1,2),(SPUTUM(ISUB,%
IRUN,J),J=1,2),(SBPAIN(ISUB,IRUN,J),J=1,2),(DYSPNE(ISUB,IRUN,J),%
J=1.2),(FATIG(ISUB,IRUN,J),J=1,2),(HEADAC(ISUB,IRUN,J),J=1,2),(SORETH%
(ISUB,IRUN,J),J=1.2),(LARYNG(ISUB,IRUN,J),J=1,2),(NASAL(ISUB,IRUN,J),%
J=1,2),(EYEIRR(ISUB,IRUN,J),J=1,2)
7915 FORMAT(I2,I3,I5,2F5.1,22I2)
IF (ISUB.NE.NAME) STOP 8
IF (IRUN.NE.RUN) STOP 9
IF (REC.NE.2) STOP 10
READ (11,7920) NAME,RUN,REC,((BLOOD(ISUB,IRUN,ITEST,ITYPE),ITYPE=1,2),%
ITEST=1,4),(HEART(ISUB,IRUN,ITEST),ITEST=1,4),MAPHR(ISUB,IRUN),%
(EKG(ISUB,IRUN,ITEST),ITEST=1,J)
7920 FORMAT(I2,I3,I5,8I4,4I4,I4,5I2)
IF (ISUB.NE.NAME) STOP 11
IF (IRUN.NE.RUN) STOP 12
IF ( EC.NE.3) STOP 13
READ(11,7925) NAME,RUN,REC,(STOP(ISUB,IRUN,ITEST),ITEST=1,4),%
ITIME(ISUB,IRUN)
7925 FDRMAT(I2,I3,I5,4I2,F6.1)
IF (ISUB.NE.NAME) STOP 14
IF (IRUN.NE.RUN) STOP 15
IF (REC.NE.4) STOP 16
READ (11,7930) NAME,RUN,REC,(PULMON(ISUB,IRUN,ITEST ),ITEST=1,4)
7930 FORMAT(I2,I3,I5,4F7.2)
IF (ISUB.NE.NAME)STOP 17
IF (IRUN.NE.RUN) STOP 18
IF (REC.NE.5) STOP 19
READ (11,7932) NAME,RUN,REC,(PULMON(ISUB,IRUN,ITEST ),  %
ITEST=5,8)
7932 FORMAT (I2,I3,I5,4F7.2)
IF (ISUB.NE.NAME) STOP 20
IF (IRUN.NE.RUN) STOP 21
IF (REC.NE.6) STOP 22
READ (11.7933)NAME,RUN,REC, (PULMON(ISUB,IRUN,ITEST ),  ITEST=9%
,12)
7933 FORMAT (I2,I3,I5,4F7.2)
IF (ISUB.NE.NAME) STOP 23
IF (IRUN.NE.RUN) STOP 24
IF (REC.NE.7) STOP 25
READ(11,7935)NAME,RUN,REC,COSITU(ISUB,IRUN),COAMBI(ISUB,IRUN),%
O3AMBI(ISUB,IRUN),TPAMBI(ISUB,IRUN),NO3SIT(ISUB,IRUN),%
SO4SIT(ISUB,IRUN)
7935 FORMAT (I2,I3,I5,2F5.1,2I4,2F5.1)
IF (ISUB.NE.NAME) STOP 26
```

APPENDIX A(3)

EXHIBIT 6

(Continued)

```
IF (REC.NE.8) STOP 28
2000 CONTINUE
3000 CONTINUE
DO 9000 ISUB=1,10
WRITE(3,9901)
9901 FORMAT ('1',131('*')/29X,'*',11X,'*',10X,'*'/%
7X,'NAME OF SUBJECT:',6X,'*',11X,'*',10X,'*',%
35X,'RUN NUMBER'/29X,'*',11X,'*',10X,'*'/%
29X,'*',11X,'*',10X,'*',79('*')/29X,'*',%
11X,'*',10X,'*',7(9X,'*'))
WRITE(3,9905) (ANAME(ISUB,J),J=1,7)
9905 FORMAT(1X,7A4,'*',1X,'SCREENING',1X,'*',%
1X,'BASELINE',1X,'*',4X,'1',4X,'*',4X,'2',4X,'*',4X,'3',4X,'*',4X,'4',%
4X,'*',4X,'5',4X,'*',4X,'6',4X,'*',4X,'7',4X,'*',4X,'8'/%
29X,'*',11X,'*',10X,'*',7(9X,'*')/1X,131('*'))
WRITE(3,9910) ((IBLOOD(ISUB,1,J,ITYPE),ITYPE=1,2),J=1,2),%
((BLOOD(ISUB,RUN,1,ITYPE),ITYPE=1,2),RUN=1,8)
9910 FORMAT(29X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,'BLOOD PRESSURE',14X,'*',11X,'*',10X,'*',%
7(9X,'*')/1X,14('.'),14X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'PRE-EXERCISE',%
12X,'*',2X,I3,'/',I3,2X,'*',2X,I3,'/',I3,1X,8('*',1X,I3,'/',I3,1X)/1X,%
131('*'))
WRITE(3,9915) ((IBLOOD(ISUB,2,J,ITYPE),ITYPE=1,2),J=1,2),%
((BLOOD(ISUB,RUN,2,ITYPE),ITYPE=1,2),RUN=1,8)
9915 FORMAT(29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'HIGHEST STAGE TAKEN',%
5X,'*',2X,I3,'/',I3,2X,'*',2X,I3,'/',I3,1X,8('*',1X,I3,'/',I3,1X)/1X,%
131('*'))
WRITE(3,9920) ((IBLOOD(ISUB,3,J,ITYPE),ITYPE=1,2),J=1,2),%
((BLOOD(ISUB,RUN,3,ITYPE),ITYPE=1,2),RUN=1,8)
9920 FORMAT(29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'30-SECOND RECOVERY TIME',%
1X,'*',2X,I3,'/',I3,2X,'*',2X,I3,'/',I3,1X,8('*',1X,I3,'/',I3,1X)/1X,%
131('*'))
WRITE(3,9925) ((IBLOOD(ISUB,4,J,ITYPE),ITYPE=1,2),J=1,2),%
((BLOOD(ISUB,RUN,4,ITYPE),ITYPE=1,2),RUN=1,8)
9925 FORMAT(29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'5-MINUTE RECOVERY TIME',%
2X,'*',2X,I3,'/',I3,2X,'*',2X,I3,'/',I3,1X,8('*',1X,I3,'/',I3,1X)/1X,%
131('*'))
WRITE(3,9935) (IHEART(ISUB,1,J),J=1,2), (HEART(ISUB,%
IRUN,1),IRUN=1,8)
9935 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,'HEART RATE',18X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,10('.'),18X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'PRE-EXERCISE',12X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9940) (IHEART(ISUB,2,J),J=1,2),(HEART(ISUB,%
IRUN,2),IRUN=1,8)
9940 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'PEAK',20X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9945) (IHEART(ISUB,3,J),J=1,2) ,(HEART(ISUB,%
IRUN,3),IRUN=1,8)
9945 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'30-SECOND RECOVERY TIME',1X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9950) (IHEART(ISUB,4,J),J=1,2)  ,(HEART(ISUB,%
IRUN,4),IRUN=1,8)
9950 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'5-MINUTE RECOVERY TIME',2X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9930)(IMAPHR(ISUB,J),J=1,2),(MAPHR(ISUB,IRUN),IRUN=1,8)
9930 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,'MAPHR',23X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,5('.'),23X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'PEAK',20X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9955) (IEKG(ISUB,J,1),J=1,2) ,(EKG%
(ISUB,IRUN,1),IRUN=1,8)
9955 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,'EKG CHANGES',17X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,11('.'),17X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'ST-T DISPLACEMENT',7X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9960) (IEKG(ISUB,J,2),J=1,2),(EKG(ISUB,IRUN,2),IRUN=1,8)
9960 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'FREQUENT PVC-S >7/MIN',3X,'*',4X,I3,4X,'*',3X,I3,4X,%
8('*',3X,I3,3X)/131('*'))
WRITE(3,9965) (IEKG(ISUB,J,3),J=1,2) ,(EKG%
(ISUB,IRUN,3),IRUN=1,8)
9965 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'VENTR. TACHYCARDIA',6X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9970) (IEKG(ISUB,J,4),J=1,2) ,(EKG%
(ISUB,IRUN,4),IRUN=1,8)
9970 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'ATRIO/IDIO VENTR. BLOCK',1X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9975) (IEKG(ISUB,J,5),J=1,2) ,(EKG%
(ISUB,IRUN,5),IRUN=1,8)
9975 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'OTHER',19X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITE(3,9980)(ISTOP(ISUB,1,J),J=1,2),(STOP(ISUB,IRUN,1),IRUN=1,8)
```

APPENDIX A(4)

EXHIBIT 6

(Continued)

```
9980 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,'STOPPING COOES',14X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,14('.'),14X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'SYMPTOMS',16X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITF(3,9985)(ISTOP(ISUB,2,J),J=1,2),(STOP(ISUB,IRUN,2),IRUN=1,8)
9985 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'SIG. EKG CHANGES',8X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITF(3,9990)(ISTOP(ISUB,3,J),J=1,2),(STOP(ISUB,IRUN,3),IRUN=1,8)
9990 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'SYSTOLIC B.P.>225 MM HG',1X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/131('*'))
WRITF(3,9995)(ISTOP(ISUB,4,J),J=1,2),(STOP(ISUB,IRUN,4),IRUN=1,8)
9995 FORMAT (29X,'*',)1X,'*',10X,'*',7(9X,'*')/%
5X,'DIASTOLIC B.P.>RESTING',2X,'*',4X,I3,4X,'*',3X,I3,4X,8('*',3X,I3,3X)/%
1X,'BY 20 MM HG OR MORE',9X,'*',11X,'*',10X,'*',7(9X,'*')/%
1X,131('*'))
WRITF(3,10000) (FITIME(ISUB,J),J=1,2),(ITIME(ISUB,IRUN),IRUN=1,8)
)0000 FORMAT (29X,'*',11X,'*',10X,'*',7(9X,'*')/%
5X,'TOTAL ELAPSEO TIME',6X,'*',2X,F6.1,3X,'*',2X,F6.1,%
2X,8('*',1X,F6.1,2X)/131('*'))
9000 CONTINUE
DO )1000 ISUB=1,10
WRITF(4,10050) (ANAME(ISUB,J),J=1,7)
10050 FORMAT('1',1X,'NAME OF SUBJECT:'/1X,7A4)
WRITF(4,10055)
10055 FORMAT(57X,'SYMPTOM CHECK LIST'/57X,18('*')/27X,'*',%
7()1X,'*')/27X,'*',3X,%
'RUN 1',3X,'*',3X,'RUN 2',3X,'*',3X,'RUN 3',3X,'*',3X,%
'RUN 4',3X,'*',3X,'RUN 5',3X,'*',3X,'RUN 6',3X,'*',3X,%
'RUN 7',3X,'*',3X,'RUN 8',3X,'*'/)
WRITE(4,10056) (AMODE(ISUB,IRUN),ACOMID(ISUB,IRUN),AROUTE(ISUB,IRUN),%
NT)ME(ISUB,IRUN),IRUN=1,8)
10056 FORMAT(20X,'COOE',3X,'*',8(1X,3A2,I3,1X,'*')/23X,' ',3X,%
'*',/(11X,'*')/20X,'DATE',3X,%
'*',8()X,9('.'),1X,'*')/27X,'*',16(5X,'*')/27X,'*',%
8(1X,'PRE',1X,'*',1X,'POST','*')/131('*'))
WRITE(4,10060) ((PULSE(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10060 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'PULSE',19X,%
'*',16(1X,I3,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10065) ((ORALTE(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10065 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'ORAL TEMPERATURE',8X,%
'*',16(F5.1,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10070) ((RESPIR(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10070 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'RESPIRATION',13X,%
'*',16(1X,I3,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITF(4,10075) ((WEIGHT(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10075 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'WEIGHT',18X,%
'*',16(F5.1,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10080) ((COHG(ISUB,IRUN,J),J=1,2),IRUN=1,8)
)0080 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'COHB',20X,%
'*',)6(2X,F3.1,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10085) ((COUGH(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10085 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'COUGH',19X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10090) ((WHEEZE(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10090 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'WHEEZE',18X,%
'*',)6(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10095) ((SPUTUM(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10095 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'SPUTUM',18X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10100) ((SBPAIN(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10100 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'SUBSTERNAL PAIN',9X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10105) ((DYSPNE(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10105 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'DYSPNEA',17X,%
'*',)6(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITF(4,10110) ((FATIG(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10110 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'FATIGUE',17X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10115) ((HEADAC(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10115 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'HEADACHE',16X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10120) ((SORETH(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10120 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'SORE THROAT',13X,%
'*',)6(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10125) ((LARYNG(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10125 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'LARYNGEAL IRRITATION',4X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10130) ((NASAL(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10130 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'NASAL DISCHARGE',9X,%
'*',)6(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
WRITE(4,10135) ((EYEIRR(ISUB,IRUN,J),J=1,2),IRUN=1,8)
10135 FORMAT(1X,'*',20X,17(5X,'*')/1X,'*',1X,'EYE IRRITATION',10X,%
'*',16(2X,I2,1X,'*')/1X,'*',20X,17(5X,'*')/131('*'))
11000 CONTINUE
DO 12000 ISUB=1,10
WRITE(8,10200) (ANAME(ISUB,J),J=1,6)
10200 FORMAT('1',25X,'***',20X,'PULMONARY VALUES',20X,'***'///%
```

APPENDIX A(5)

EXHIBIT 6

(Continued)

```
      4X,'NAME OF SUBJECT:'//%
      1X,6A4,2X,'*',1X,'SCREENING',1X,'*',1X,'BASELINE',2X,%
      '*',1X,'RUN 1',1X,'*',1X,'RUN 2',1X,'*',%
      1X,'RUN 3',1X,'*',1X,'RUN 4',1X,'*',1X,'RUN 5',1X,'*',%
      1X,'RUN 6'1X,'*',1X,'RUN 7',1X,'*',1X,'RUN 8'/120('*'))
      WRITE(8,10205) (PULPRE(ISUB,1,J),J=1,2),(PULMON(ISUB,IRUN,1 ),IRUN=1,8 )
10205 FORMAT(1X,'FORCED VITAL CAPACITY, LT.', '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,F4.2,3X,'*',4X,F4.2,3X,'*',2X,F4.2,1X,7('*',2X,F4.2,1X)/120('*'))
      WPITF(8,10210) (PULPRE(ISUB,2,J),J=1,2),(PULMON(ISUB,IRUN,2),IRUN=1,8)
10210 FORMAT(1X,'% OF PREDICTED FVC',8X, '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,I4,3X,'*',4X,I4,3X,'*',2X,I3,2X,7('*',2X,I3,2X)/120('*'))
      WRITF(8,10215) (PULPRE(ISUB,3,J),J=1,2),(PULMON(ISUB,IRUN,3),IRUN=1,8)
10215 FORMAT(1X,'1-SEC FORCED',14X,2('*',11X),8('*',7X)/%
      1X,'FXPIRATORY VOLUME, LT.',4X,%
      '*',4X,F4.2,3X,'*',4X,F4.2,3X,'*',2X,F4.2,1X,7('*',2X,F4.2,1X)/120('*'))
      WPITF(8,10220) (PULPRE(ISUB,4,J),J=1,2),(PULMON(ISUB,IRUN,4),IRUN=1,8)
10220 FORMAT(1X,'% OF PREDICTED FEV-1',6X, '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,I4,3X,'*',4X,I4,3X,'*',2X,I3,2X,7('*',2X,I3,2X)/120('*'))
      WRITE(8,10225) (PULPRE(ISUB,5,J),J=1,2),(PULMON(ISUB,IRUN,5),IRUN=1,8)
10225 FORMAT(1X,'FEV-1/FVC, %',14X, '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,I4,3X,'*',4X,I4,3X,'*',2X,I3,2X,7('*',2X,I3,2X)/120('*'))
      WRITE(8,10230) (PULPRE(ISUB,6,J),J=1,2),(PULMON(ISUB,IRUN,6),IRUN=1,8)
10230 FORMAT(1X,'FEV-3/FVC, %',14X, '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,I4,3X,'*',4X,I4,3X,'*',2X,I3,2X,7('*',2X,I3,2X)/120('*'))
      WRITE(8,10235) (PULPRE(ISUB,7,J),J=1,2),(PULMON(ISUB,IRUN,7),IRUN=1,8)
10235 FORMAT(1X,'PEAK EXPIRATORY FLOW',6X,2('*',11X),8('*',7X)/%
      1X,'LT./MIN.',18X,2('*',4X,I4,3X),%
      8('*',2X,I3,2X)/120('*'))
      WRITF(8,10240) (PULPRE(ISUB,8,J),J=1,2),(PULMON(ISUB,IRUN,8),IRUN=1,8)
10240 FORMAT(1X,'% OF PREOICTEO PF',9X,2('*',11X),8('*',7X)/%
       27X,2('*',4X,I4,3X),%
      8('*',2X,I3,2X)/120('*'))
      WRITE(8,10245) (PULPRE(ISUB,9,J),J=1,2),(PULMON(ISUB,IRUN,9),IRUN=1,8)
10245 FORMAT(1X,'FORCEO EXP. FLOW @',8X,2('*',11X),8('*',7X)/%
      1X,'50% OF FVC',16X,%
      '*',4X,I4,3X,'*',4X,I4,3X,8('*',2X,I3,2X)/120('*'))
      WRITF(8,10250) (PULPRE(ISUB,10,J),J=1,2),(PULMON(ISUB,IRUN,10),IRUN=1,8)
10250 FORMAT(1X,'FEF25-75% L/MIN',11X, '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,I4,3X,'*',4X,I4,3X,'*',2X,I3,2X,7('*',2X,I3,2X)/120('*'))
      WPITE(8,10255) (PULPRE(ISUB,11,J),J=1,2),(PULMON(ISUB,IRUN,11),IRUN=1,8)
10255 FORMAT(1X,'% OF PREDICTED FEF   ',6X, '*',11X,'*' ,%
      11X,'*',7(7X,'*')/27X,%
      '*',4X,I4,3X,'*',4X,I4,3X,'*',2X,I3,2X,7('*',2X,I3,2X)/120('*'))
)2000 CONTINUE
      DO 12500 ISUB=1,10
      WRITE(7,12005) (ANAME(ISUB,J),J=1,7)
12005 FORMAT('1',3(30X,'*')//53X,'POLLUTANT CONCENTRATIONS'//%
      1X,3(30X,'*')/5X,'NAME OF SUBJECT:'/1X,7A4/22X,8('*',8X)/%
      22X,'*',2X,'RUN 1',1X,'*',2X,'RUN 2',1X,'*',2X,'RUN 3',1X,'*',%
      2X,'RUN 4',1X,'*',2X,'RUN 5',1X,'*',2X,'RUN 6',1X,'*',2X,'RUN 7',%
      1X,'*',2X,'RUN 8'/94('*'))
      WRITE(7,12010) (COSITU(ISUB,IRUN),IRUN=1,8),(COAMBI(ISUB,IRUN),IRUN=1,8),%
      (O3AMBI(ISUB,IRUN),IRUN=1,8),(NO3SIT%
      (ISUB,IRUN),IRUN=1,8),(SO4SIT(ISUB,IRUN),IRUN=1,8)
12010 FORMAT(22X,'*',7(8X,'*')/1X,'CARBON MONOXIOE, PPM',1X,%
      8('*',2X,F4.1,2X)/10X,'IN SITU',5X,'*',7(8X,'*')/%
      94('*')/22X,'*',7(8X,'*')/%
      1X,'CARBON MONOXIOE, PPM',1X,8('*',2X,F4.1,2X)/22X,'*',7(8X,'*')/%
      94('*')/22X,'*',7(8X,'*')/1X,'OZONE, PPB',11X,8('*',2X,I3,3X)/%
      22X,'*',7(8X,'*')/94('*')/22X,'*',7(8X,'*')/1X,%
      'NITRATES, UG/CM',6X,8('*',2X,F4.1,2X)/22X,'*',7(8X,'*')/94('*')/%
      22X,'*',7(8X,'*')/1X,'SULFATES, UG/CM',6X,8('*',2X,F4.1,2X)/22X,'*',%
      7(8X,'*')/94('*')//%
      4X,' '/4X,'PPB- PARTS PER BILLION'/4X,'PPM- PARTS PER MILLION'/%
      4X,'UG/CM- MICROGRAMS PER CUBIC METER')
12500 CONTINUE
      STOP
      END
```

APPENDIX A(6)

EXHIBIT 7

Cardiovascular Data

NAME OF SUBJECT: B1	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	124/ 70	130/ 80	120/ 70	120/ 65	110/ 70	120/ 78	118/ 70	110/ 60	112/ 70	125/ 80
HIGHEST STAGE TAKEN	160/ 70	160/ 70	130/ 68	144/ 64	140/ 64	162/ 68	136/ 68	140/ 70	164/ 60	150/ 70
30-SECOND RECOVERY TIME	148/ 68	175/ 70	154/ 60	170/ 60	164/ 64	158/ 88	154/ 68	135/ 60	188/ 76	170/ 60
5-MINUTE RECOVERY TIME	112/ 68	145/ 60	128/ 55	130/ 60	120/ 70	0/ 0	118/ 60	125/ 70	118/ 60	125/ 70
HEART RATE										
PRE-EXERCISE	68	70	86	100	104	105	120	94	90	97
PEAK	180	188	178	184	190	190	192	180	190	190
30-SECOND RECOVERY TIME	160	162	144	162	164	163	160	160	172	158
5-MINUTE RECOVERY TIME	116	114	98	108	110	118	114	115	120	108
MAPHR										
PEAK	200	200	200	200	200	200	200	200	200	200
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IOIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	O	O	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	780.0	775.0	807.0	820.0	825.0	765.0	755.0	780.0	820.0	800.0

APPENDIX A(7)

EXHIBIT 7

(Continued)

NAME OF SUBJECT: B2	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	118/ 88	120/ 80	106/ 72	122/ 64	150/ 90	100/ 80	122/ 60	130/ 70	120/ 60	114/ 78
HIGHEST STAGE TAKEN	156/ 68	156/ 80	160/ 80	148/ 78	134/ 78	126/ 76	140/ 70	120/ 70	168/ 64	154/ 76
30-SECOND RECOVERY TIME	210/ 72	210/ 84	206/ 78	198/ 78	164/ 80	210/ 78	185/ 60	200/ 60	200/ 60	200/ 70
5-MINUTE RECOVERY TIME	130/ 70	118/ 60	144/ 60	0/ 0	122/ 76	122/ 60	130/ 70	130/ 80	0/ 0	120/ 70
HEART RATE										
PRE-EXERCISE	52	46	75	68	58	72	62	65	90	67
PEAK	195	188	193	193	190	190	190	189	180	194
30-SECOND RECOVERY TIME	160	148	150	178	155	155	133	152	160	152
5-MINUTE RECOVERY TIME	103	94	95	108	98	90	88	100	85	100
MAPHR										
PEAK	196	196	196	196	196	196	196	196	196	196
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	1025.0	1058.0	1045.0	1085.0	1045.0	1080.0	997.0	1100.0	1050.0	1025.0

APPENDIX A(8)

EXHIBIT 7

(Continued)

NAME OF SUBJECT: B3	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	94/ 60	120/ 58	110/ 70	104/ 62	0/ 0	110/ 65	90/ 60	0/ 0	100/ 56	100/ 58
HIGHEST STAGE TAKEN	124/ 60	124/ 68	122/ 64	150/ 60	0/ 0	115/ 70	120/ 80	0/ 0	140/ 74	134/ 70
30-SECOND RECOVERY TIME	172/ 58	158/ 72	160/ 80	195/ 80	0/ 0	180/ 70	0/ 0	0/ 0	188/ 64	142/ 70
5-MINUTE RECOVERY TIME	108/ 54	112/ 58	120/ 60	110/ 60	0/ 0	105/ 60	0/ 0	0/ 0	118/ 62	110/ 58
HEART RATE										
PRE-EXERCISE	50	58	43	50	0	58	73	0	56	62
PEAK	176	160	170	180	0	180	175	0	160	174
30-SECOND RECOVERY TIME	150	110	138	125	0	145	145	0	133	169
5-MINUTE RECOVERY TIME	75	64	78	60	0	80	87	0	68	60
MAPHR										
PEAK	199	199	199	199	0	199	199	0	199	199
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	0	1	1	0	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	1200.0	1080.0	855.0	880.0	0.	845.0	790.0	0.	720.0	800.0

APPENDIX A(9)

EXHIBIT 7

(Continued)

NAME OF SUBJECT:			RUN NUMBER							
B4	SCREENING	BASELINE	1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	132/ 70	132/ 84	125/ 90	122/ 78	120/ 88	138/ 84	150/ 90	120/ 74	130/ 80	124/ 76
HIGHEST STAGE TAKEN	142/ 88	170/ 82	130/ 80	158/ 74	152/ 72	164/ 80	150/ 75	144/ 64	170/ 70	162/ 86
30-SECOND RECOVERY TIME	184/ 50	200/ 86	190/ 80	200/ 70	184/ 62	212/ 88	180/ 80	186/ 72	190/ 88	200/ 78
5-MINUTE RECOVERY TIME	170/ 48	122/ 60	130/ 70	114/ 78	110/ 70	120/ 80	128/ 70	148/ 70	132/ 68	126/ 68
HEART RATE										
PRE-EXERCISE	55	66	63	60	67	65	73	75	74	68
PEAK	180	184	180	185	175	182	186	180	184	180
30-SECOND RECOVERY TIME	170	162	157	152	154	155	150	160	158	160
5-MINUTE RECOVERY TIME	96	90	90	89	79	90	96	93	94	88
MAPHR										
PEAK	184	184	184	184	184	184	184	184	184	184
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	1	0	1	0	1
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	735.0	728.0	761.0	753.0	747.0	728.0	738.0	715.0	735.0	733.0

NAME OF SUBJECT: B5	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	128/ 62	138/ 76	125/ 78	138/ 64	128/ 68	110/ 70	128/ 80	125/ 80	130/ 70	118/ 78
HIGHEST STAGE TAKEN	166/ 64	154/ 68	150/ 75	164/ 70	152/ 66	130/ 70	164/ 70	150/ 60	150/ 70	148/ 74
30-SECOND RECOVERY TIME	170/ 74	190/ 60	190/ 65	180/ 70	190/ 60	195/ 60	180/ 70	185/ 60	200/ 70	200/ 74
5-MINUTE RECOVERY TIME	140/ 60	150/ 58	140/ 75	124/ 68	140/ 70	135/ 60	114/ 78	120/ 70	136/ 60	140/ 60
HEART RATE										
PRE-EXERCISE	74	60	82	86	73	90	112	92	77	80
PEAK	196	200	192	194	196	190	198	196	198	188
30-SECOND RECOVERY TIME	161	180	160	160	164	135	155	166	164	133
5-MINUTE RECOVERY TIME	110	120	94	100	98	103	120	109	106	95
MAPHR										
PEAK	202	202	202	202	202	202	202	202	202	202
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	878.0	923.0	805.0	800.0	812.0	787.0	780.0	793.0	843.0	748.0

APPENDIX A(11)

EXHIBIT 7

(Continued)

NAME OF SUBJECT: B6	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	120/ 80	120/ 74	112/ 78	120/ 90	128/ 78	115/ 74	100/ 70	90/ 70	102/ 68	100/ 70
HIGHEST STAGE TAKEN	150/ 70	150/ 70	132/ 70	115/ 70	152/ 70	130/ 72	110/ 80	115/ 60	112/ 60	124/ 60
30-SECOND RECOVERY TIME	155/ 60	168/ 64	150/ 78	0/ 0	174/ 74	130/ 62	150/ 60	140/ 60	154/ 58	160/ 40
5-MINUTE RECOVERY TIME	138/ 70	122/ 54	108/ 70	105/ 70	118/ 60	100/ 68	120/ 60	95/ 65	110/ 60	0/ 0
HEART RATE										
PRE-EXERCISE	66	60	92	92	107	100	103	95	75	84
PEAK	190	190	195	187	180	190	190	190	190	199
30-SECOND RECOVERY TIME	0	185	170	154	165	183	145	166	0	0
5-MINUTE RECOVERY TIME	115	100	110	103	115	110	105	108	120	110
MAPHR										
PEAK	193	193	193	193	193	193	193	193	193	193
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	1	1	1	1	1	1	1	1	1	1
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	868.0	900.0	835.0	797.0	810.0	847.0	815.0	825.0	900.0	877.0

APPENDIX A(12)

EXHIBIT 7

(Continued)

NAME OF SUBJECT: B7	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	106/ 80	125/ 95	110/ 80	104/ 72	138/ 90	114/ 78	128/ 86	105/ 80	110/ 88	104/ 80
HIGHEST STAGE TAKEN	160/ 84	168/ 85	162/ 80	162/ 76	155/ 80	138/ 80	170/ 80	156/ 82	162/ 80	140/ 75
30-SECOND RECOVERY TIME	186/ 90	210/100	190/ 90	168/ 80	185/ 60	160/ 86	180/ 86	180/ 80	190/ 94	190/ 90
5-MINUTE RECOVERY TIME	130/ 76	144/ 80	120/ 80	110/ 74	134/ 82	120/ 80	120/ 90	120/ 70	134/ 80	138/ 80
HEART RATE										
PRE-EXERCISE	56	60	70	60	75	63	65	71	60	58
PEAK	190	194	190	180	165	189	180	186	190	186
30-SECOND RECOVERY TIME	180	150	178	165	85	155	170	150	0	148
5-MINUTE RECOVERY TIME	94	93	98	104	83	92	70	85	107	80
MAPHR										
PEAK	194	194	194	194	194	194	194	194	194	194
EKG CHANGES										
ST-T DISPLACEMENT	1	1	1	1	1	1	1	1	1	1
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	900.0	840.0	900.0	835.0	860.0	843.0	720.0	830.0	925.0	835.0

APPENDIX A(13)

EXHIBIT 7

(Continued)

NAME OF SUBJECT: M1	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	0/ 0	140/ 70	120/ 74	130/ 70	104/ 60	112/ 70	140/ 60	138/ 78	122/ 78	125/ 65
HIGHEST STAGE TAKEN	180/ 84	168/ 80	150/ 64	158/ 75	162/ 74	198/ 68	168/ 68	170/ 70	170/ 60	160/ 70
30-SECOND RECOVERY TIME	200/ 86	220/ 78	195/ 72	200/ 70	190/ 64	206/ 78	210/ 70	190/ 60	186/ 70	170/ 80
5-MINUTE RECOVERY TIME	0/ 0	175/ 65	144/ 62	142/ 55	148/ 56	170/ 68	190/ 70	130/ 60	140/ 90	140/ 70
HEART RATE										
PRE-EXERCISE	62	72	47	47	60	58	81	53	66	48
PEAK	190	188	178	180	184	175	190	183	180	184
30-SECOND RECOVERY TIME	0	170	164	164	165	160	173	175	175	166
5-MINUTE RECOVERY TIME	108	117	90	89	90	100	101	100	88	98
MAPHR										
PEAK	201	201	201	201	201	201	201	201	201	201
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	893.0	921.0	942.0	945.0	943.0	905.0	935.0	935.0	890.0	933.0

APPENDIX A(14)

EXHIBIT 7

(Continued)

NAME OF SUBJECT: M2	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	100/ 62	102/ 60	0/ 0	110/ 78	104/ 76	108/ 60	108/ 60	105/ 70	100/ 75	100/ 68
HIGHEST STAGE TAKEN	164/ 78	148/ 80	160/ 75	170/ 68	118/ 68	128/ 74	152/ 70	125/ 65	130/ 62	156/ 70
30-SECOND RECOVERY TIME	168/ 80	140/ 62	150/ 60	155/ 68	154/ 72	164/ 76	160/ 70	160/ 70	150/ 70	180/ 68
5-MINUTE RECOVERY TIME	128/ 70	130/ 70	0/ 0	128/ 78	120/ 72	118/ 72	108/ 60	100/ 70	110/ 75	134/ 78
HEART RATE										
PRE-EXERCISE	58	63	70	50	68	52	50	49	60	48
PEAK	185	182	189	175	182	183	182	184	165	190
30-SECOND RECOVERY TIME	168	168	160	175	155	155	154	160	135	160
5-MINUTE RECOVERY TIME	98	108	103	85	90	90	88	90	80	87
MAPHR										
PEAK	198	198	198	198	198	198	198	198	198	198
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	780.0	762.0	822.0	760.0	763.0	774.0	773.0	780.0	770.0	770.0

NAME OF SUBJECT: M3	SCREENING	BASELINE	RUN NUMBER 1	2	3	4	5	6	7	8
BLOOD PRESSURE										
PRE-EXERCISE	122/ 74	112/ 62	112/ 60	120/ 80	120/ 70	102/ 80	120/ 80	108/ 58	132/ 84	0/ 0
HIGHEST STAGE TAKEN	130/ 72	170/ 70	158/ 60	158/ 0	124/ 62	140/ 80	155/ 70	142/ 68	140/ 70	168/ 70
30-SECOND RECOVERY TIME	158/ 78	190/ 78	170/ 70	185/ 80	180/ 70	185/ 80	160/ 70	188/ 60	185/ 75	198/ 70
5-MINUTE RECOVERY TIME	128/ 74	134/ 68	124/ 60	146/ 70	130/ 64	0/ 0	0/ 0	124/ 70	125/ 60	138/ 70
HEART RATE										
PRE-EXERCISE	71	74	64	71	83	76	65	90	70	80
PEAK	195	190	192	180	191	194	195	199	193	198
30-SECOND RECOVERY TIME	190	160	155	165	160	168	164	160	160	184
5-MINUTE RECOVERY TIME	100	95	94	100	90	0	97	100	92	105
MAPHR										
PEAK	197	197	197	197	197	197	197	197	197	197
EKG CHANGES										
ST-T DISPLACEMENT	0	0	0	0	0	0	0	0	0	0
FREQUENT PVC-S >7/MIN	0	0	0	0	0	0	0	0	0	0
VENTR. TACHYCARDIA	0	0	0	0	0	0	0	0	0	0
ATRIO/IDIO VENTR. BLOCK	0	0	0	0	0	0	0	0	0	0
OTHER	0	0	0	0	0	0	0	0	0	0
STOPPING CODES										
SYMPTOMS	1	1	1	1	1	1	1	1	1	1
SIG. EKG CHANGES	0	0	0	0	0	0	0	0	0	0
SYSTOLIC B.P.>225 MM HG	0	0	0	0	0	0	0	0	0	0
DIASTOLIC B.P.>RESTING BY 20 MM HG OR MORE	0	0	0	0	0	0	0	0	0	0
TOTAL ELAPSED TIME	900.0	940.0	934.0	935.0	920.0	970.0	942.0	900.0	930.0	975.0

APPENDIX A(16)

EXHIBIT 8

Symptom Check Lists Data

NAME OF SUBJECT: B1

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 1 W 30		B 1 W 60		B 1 X 30		B 1 X 60		B 1 Y 30		B 1 Y 60		B 1 Z 30		B 1 Z 60	
DATE	....		....		....		....		....		....		....		....	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	52	60	68	88	60	100	72	104	60	72	80	112	72	88	76	96
ORAL TEMPERATURE	97.0	98.0	97.0	98.0	98.0	98.0	97.6	98.0	98.0	98.0	98.2	98.0	98.0	97.4	98.0	98.6
RESPIRATION	14	16	16	18	16	16	16	20	16	20	20	20	20	16	16	20
WEIGHT	143.5	142.5	142.5	141.5	141.8	140.8	141.0	140.3	141.5	140.5	139.8	139.0	140.8	140.3	142.3	140.3
COHB	0.	1.5	2.0	2.0	1.0	1.0	0.	0.	.5	0.	0.	0.	2.0	2.5	1.0	2.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	1	1	0	1	0	0	0	2	1	1	1	1	1	1	1	1
HEADACHE	1	1	1	0	0	1	0	0	0	1	0	0	0	0	0	1
SORE THROAT	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
LARYNGEAL IRRITATION	1	1	0	1	0	1	1	1	0	1	0	0	0	0	1	2
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	1	1	0	1	0	1	0	1	0	1	0	1	0	1	0	2

NAME OF SUBJECT:

B2

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 2 W 30		B 2 W 60		B 2 X 30		B 2 X 60		B 2 Y 30		B 2 Y 60		B 2 Z 30		B 2 Z 60	
DATE																
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	52	64	56	64	52	60	52	56	52	60	48	72	60	68	60	62
ORAL TEMPERATURE	98.6	98.0	97.8	98.4	98.8	99.0	98.6	98.2	98.0	98.8	98.4	98.6	98.0	99.4	98.0	98.0
RESPIRATION	16	20	20	20	20	24	16	20	16	20	16	20	16	16	14	18
WEIGHT	167.0	166.5	168.0	166.8	166.0	164.3	169.3	167.0	167.0	164.5	170.8	169.0	167.0	165.8	164.8	164.0
COHB	.5	1.0	0.	1.0	0.	1.5	0.	2.0	1.5	1.5	1.0	0.	3.0	0.	1.0	2.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	2
HEADACHE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SORE THROAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LARYNGEAL IRRITATION	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

APPENDIX A(18)

EXHIBIT 8

(Continued)

NAME OF SUBJECT:

B3

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 3 W 30		B 3 W 60		0		B 3 X 60		B 3 Y 30		0		B 3 Z 30		B 3 Z 60	
DATE																
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	56	64	52	48	0	0	52	68	60	66	0	0	56	56	60	64
ORAL TEMPERATURE	98.6	98.0	97.8	98.0	0.	0.	97.0	98.0	98.0	98.0	0.	0.	98.6	98.0	98.2	98.2
RESPIRATION	28	32	24	28	0	0	16	20	16	16	0	0	20	20	20	24
WEIGHT	154.8	154.3	156.0	154.5	0.	0.	155.3	153.5	153.5	152.0	0.	0.	155.5	153.3	153.5	152.3
COHB	0.	1.0	0.	0.	0.	0.	0.	2.0	.5	1.0	0.	0.	5.0	2.0	2.0	4.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	0	0	0	0	0	0	1	2	1	2	0	0	1	2	0	2
HEADACHE	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
SORE THROAT	0	0	0	0	0	0	0	1	0	1	0	0	0	2	0	2
LARYNGEAL IRRITATION	0	0	0	0	0	0	0	1	0	2	0	0	1	0	0	0
NASAL DISCHARGE	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	2
EYE IRRITATION	0	0	0	2	0	0	0	1	0	2	0	0	0	1	1	0

NAME OF SUBJECT:

B4

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 4 W 30		B 4 W 60		B 4 X 30		B 4 X 60		B 4 Y 30		B 4 Y 60		B 4 Z 30		B 4 Z 60	
DATE	....		....		....		....		....		....		....		....	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	56	78	52	66	56	60	56	68	60	80	48	88	60	80	56	66
ORAL TEMPERATURE	97.6	98.0	98.0	98.0	97.0	97.0	97.0	98.0	98.0	97.0	98.0	98.0	97.0	97.0	98.0	98.0
RESPIRATION	14	18	16	18	16	16	16	20	16	20	12	16	20	22	20	16
WEIGHT	183.5	182.0	183.8	182.0	184.8	183.5	185.0	183.3	183.3	182.0	185.3	183.8	185.0	184.5	183.5	182.5
COHB	3.0	3.5	0.	2.5	0.	1.5	1.0	2.0	0.	1.0	0.	1.0	0.	1.0	1.0	0.
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
FATIGUE	1	1	0	1	0	1	0	0	1	0	0	1	0	0	0	0
HEADACHE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SORE THROAT	0	0	1	1	0	0	0	2	0	1	0	0	0	1	0	1
LARYNGEAL IRRITATION	0	1	2	2	0	0	1	2	0	1	0	0	0	0	2	2
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	1	1	1	2	0	0	0	0	0	1	0	1	0	0	0	0

NAME OF SUBJECT:

B5

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 5 W 30		B 5 W 60		B 5 X 30		B 5 X 60		B 5 Y 30		B 5 Y 60		B 5 Z 30		B 5 Z 60	
DATE	....		....		....		....		....		....		....		....	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	76	100	64	80	68	92	68	72	96	120	58	108	68	72	72	86
ORAL TEMPERATURE	98.0	97.0	98.4	98.8	98.0	97.0	98.0	98.6	98.4	0.	98.0	99.0	98.0	98.0	98.2	97.0
RESPIRATION	20	20	24	28	16	20	20	24	16	28	14	20	16	18	24	28
WEIGHT	172.0	171.0	173.0	171.3	174.0	172.0	174.0	169.8	172.0	170.3	173.3	170.0	173.0	171.8	170.5	169.0
COHB	1.0	1.5	2.5	2.5	0.	1.0	0.	0.	0.	.5	0.	2.0	0.	2.5	0.	0.
COUGH	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
FATIGUE	1	2	0	0	1	1	0	1	0	1	0	2	1	1	1	0
HEADACHE	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SORE THROAT	0	0	0	1	0	1	0	2	0	1	0	1	0	1	0	2
LARYNGEAL IRRITATION	0	1	0	0	0	1	0	2	1	1	0	1	0	2	1	1
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	0	1	0	0	0	1	0	2	0	2	0	1	0	2	0	1

NAME OF SUBJECT:

B6

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 6 W 30		B 6 W 60		B 6 X 30		B 6 X 60		B 6 Y 30		B 6 Y 60		B 6 Z 30		B 6 Z 60	
DATE																
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	88	100	80	96	64	108	80	108	68	108	60	120	64	96	64	96
ORAL TEMPERATURE	97.0	97.0	98.0	98.0	98.0	97.6	98.0	98.0	97.8	97.0	98.0	98.2	97.0	98.6	97.2	98.0
RESPIRATION	18	22	20	22	15	16	14	24	18	24	16	24	14	20	16	24
WEIGHT	148.0	147.0	148.8	147.0	145.8	144.8	149.5	147.5	147.8	146.0	144.0	141.3	152.0	151.0	150.8	149.3
COHB	0.	2.0	1.0	1.0	0.	1.0	0.	0.	.5	2.0	1.0	2.0	0.	1.0	0.	1.0
COUGH	0	0	0	1	0	0	0	1	0	0	0	1	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	1	0.	0	0	1	0	0	0	1	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	1	2	1	2	0	0	0	0	0	1	0	0	0	0	0	1
HEADACHE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SORE THROAT	0	1	0	1	0	1	0	0	0	1	0	1	0	0	0	0
LARYNGEAL IRRITATION	0	1	1	2	1	0	2	1	0	1	0	1	0	0	0	0
NASAL DISCHARGE	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0
EYE IRRITATION	0	1	0	2	0	0	1	0	0	1	0	3	0	0	0	0

EXHIBIT 8

(Continued)

NAME OF SUBJECT:

B7

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	B 7 W 30		B 7 W 60		B 7 X 30		B 7 X 60		B 7 Y 30		B 7 Y 60		B 7 Z 30		B 7 Z 60	
DATE	....		....		....		....		....		....		....		....	
	PRE	POST	RRE	POST	RRE	POST	PRE	POST	PRE	POST	RRE	POST	PRE	ROST	RRE	POST
PULSE	72	80	52	60	68	84	54	80	56	80	58	68	56	52	60	104
ORAL TEMPERATURE	98.6	98.6	98.0	98.6	98.8	98.8	98.8	98.2	99.0	98.0	98.2	98.6	98.4	98.6	98.0	98.0
RESPIRATION	16	20	12	16	20	16	16	16	16	16	16	20	16	16	16	16
WEIGHT	160.5	159.3	161.0	159.5	159.8	158.5	161.3	158.5	158.3	157.8	160.5	157.8	161.8	161.0	158.8	156.8
COHB	1.5	2.5	0.	1.0	1.5	0.	1.0	1.5	0.	.5	.5	2.0	1.0	1.0	1.0	1.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	1
HEADACHE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SORE THROAT	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
LARYNGEAL IRRITATION	0	1	0	1	0	0	0	0	0	2	0	0	0	0	0	1
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	0	0	0	1	0	0	0	1	0	1	0	1	0	0	0	0

NAME OF SUBJECT:

M1

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	M 1 W 30		M 1 W 60		M 1 X 30		M 1 X 60		M 1 Y 30		M 1 Y 60		M 1 Z 30		M 1 Z 60	
DATE																
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	48	48	48	48	48	60	56	56	52	52	60	56	60	64	56	52
ORAL TEMPERATURE	98.0	98.0	97.0	97.0	98.0	98.0	97.6	98.0	98.0	98.0	97.2	97.4	98.0	97.0	97.0	97.0
RESPIRATION	14	16	12	14	12	16	16	16	16	14	20	16	20	18	14	14
WEIGHT	177.3	176.8	176.3	175.5	176.0	175.5	177.5	177.8	175.0	174.0	177.5	176.5	178.5	178.3	177.8	176.5
COHB	0.	2.5	1.0	3.0	0.	.5	2.0	0.	0.	1.0	0.	1.0	2.0	2.0	1.5	2.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0
HEADACHE	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
SORE THROAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LARYNGEAL IRRITATION	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0	0

NAME OF SUBJECT:

M2

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	M 2 W 30		M 2 W 60		M 2 X 30		M 2 X 60		M 2 Y 30		M 2 Y 60		M 2 Z 30		M 2 Z 60	
DATE	....		....		....		....		....		....		....		....	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	64	56	60	64	78	76	64	68	56	60	76	70	60	60	80	66
ORAL TEMPERATURE	98.4	98.0	97.8	97.6	98.8	98.4	98.4	98.4	98.0	98.2	98.0	98.0	98.0	98.2	98.0	98.0
RESPIRATION	24	16	16	12	16	14	16	18	16	16	16	16	16	16	20	16
WEIGHT	148.0	148.0	149.0	148.5	147.0	147.0	149.5	149.5	149.0	148.0	148.5	148.0	148.5	148.5	149.5	149.5
COHR	1.0	1.0	0.	1.0	1.0	2.0	0.	3.0	2.5	4.0	2.0	1.5	2.0	4.0	1.0	1.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	0	0	1	0	0	0	0	0	1	1	1	2	0	0	1	1
HEADACHE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SORE THROAT	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LARYNGEAL IRRITATION	0	0	0	0	1	1	0	1	0	0	0	1	0	0	0	1
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

EXHIBIT 8

(Continued)

NAME OF SUBJECT:

M3

SYMPTOM CHECK LIST

	RUN 1		RUN 2		RUN 3		RUN 4		RUN 5		RUN 6		RUN 7		RUN 8	
CODE	M 3 W 30		M 3 W 60		M 3 X 30		M 3 X 60		M 3 Y 30		M 3 Y 60		M 3 Z 30		M 3 Z 60	
DATE	....		....		....		....		....		....		....		....	
	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST	PRE	POST
PULSE	72	68	72	70	88	68	52	72	72	64	64	84	76	64	80	72
ORAL TEMPERATURE	96.2	96.0	98.2	97.8	98.0	98.0	98.0	98.0	97.0	97.2	98.0	98.0	98.0	98.0	97.0	98.6
RESPIRATION	16	20	20	20	18	20	16	18	20	20	20	20	16	16	20	20
WEIGHT	143.5	143.5	143.0	143.0	138.0	138.3	143.0	142.5	142.0	141.5	142.0	141.3	139.0	138.5	140.0	139.5
COHB	0.	1.0	2.0	0.	4.0	3.5	0.	1.0	0.	2.0	0.	4.5	0.	1.0	2.0	4.0
COUGH	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
WHEEZE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SPUTUM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SUBSTERNAL PAIN	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
DYSPNEA	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FATIGUE	1	1	0	0	0	0	0	0	0	1	1	0	1	0	0	0
HEADACHE	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
SORE THROAT	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
LARYNGEAL IRRITATION	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
NASAL DISCHARGE	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
EYE IRRITATION	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0

APPENDIX A(26)

EXHIBIT 9

Pulmonary Function Data

*** PULMONARY VALUES ***

NAME OF SUBJECT: B1

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.24	5.41	4.78	5.13	5.12	5.53	5.18	5.57	5.39	4.92
% OF PREDICTED FVC	103	107	94	101	101	109	102	110	106	97
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.17	4.24	4.03	4.20	4.21	4.57	4.41	5.03	4.28	4.01
% OF PREDICTED FEV-1	100	101	96	100	100	109	105	120	102	96
FEV-1/FVC, %	80	79	84	82	82	83	85	90	80	82
FEV-3/FVC, %	96	98	97	97	97	100	100	116	96	100
PEAK EXPIRATORY FLOW LT./MIN.	645	673	611	645	618	690	671	735	676	637
% OF PREDICTED PF	112	117	106	112	107	120	116	127	117	110
FORCED EXP. FLOW @ 50% OF FVC	301	309	284	317	318	389	364	385	321	311
FEF25-75% L/MIN	261	264	252	277	278	327	311	343	274	304
% OF PREDICTED FEF	93	94	90	99	99	116	111	122	98	110

APPENDIX A(27)

EXHIBIT 9

(Continued)

*** PULMONARY VALUES ***

NAME OF SUBJECT:
B2

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.69	5.87	5.79	6.22	5.90	5.78	5.90	6.40	6.06	5.75
% OF PREDICTED FVC	111	114	113	121	115	112	115	124	118	112
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.43	4.32	4.36	4.51	4.58	4.42	4.46	4.71	4.67	4.41
% OF PREDICTED FEV-1	106	103	104	107	109	105	106	112	111	105
FEV-1/FVC, %	78	74	75	73	78	76	76	74	77	77
FEV-3/FVC, %	98	95	97	94	97	96	96	93	96	95
PEAK EXPIRATORY FLOW LT./MIN.	641	629	632	669	647	622	652	694	676	619
% OF PREDICTED PF	110	108	109	115	111	107	112	119	116	106
FORCED EXP. FLOW @ 50% OF FVC	284	80	259	247	312	286	262	268	303	262
FEF25-75% L/MIN	241	211	229	212	267	248	219	224	250	238
% OF PREDICTED FEF	88	77	83	77	97	90	80	82	91	86

*** PULMONARY VALUES ***

NAME OF SUBJECT:
B3

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.67	5.23	5.60	5.70	0.	5.72	5.37	5.43	0.	5.84
% OF PREDICTED FVC	110	101	108	110	0	110	104	105	0	113
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.47	4.18	4.40	4.60	0.	4.59	4.44	4.34	0.	4.30
% OF PREDICTED FEV-1	106	99	104	108	0	108	104	102	0	101
FEV-1/FVC, %	79	80	79	81	0	80	83	80	0	74
FEV-3/FVC, %	96	1	97	1	0	98	100	100	0	98
PEAK EXPIRATORY FLOW LT./MIN.	545	523	568	571	0	556	572	551	0	599
% OF PREDICTED PF	93	89	97	97	0	95	98	94	0	102
FORCED EXP. FLOW @ 50% OF FVC	292	225	269	308	0	318	296	265	0	302
FEF25-75% L/MIN	268	243	256	280	0	276	278	255	0	291
% OF PREDICTED FEF	96	87	92	100	0	98	99	91	0	104

APPENDIX A(29)

EXHIBIT 9

(Continued)

*** PULMONARY VALUES ***

NAME OF SUBJECT: B4

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.13	5.17	5.38	5.18	5.17	5.53	5.30	5.21	5.11	5.16
% OF PREDICTED FVC	99	100	104	100	100	107	102	101	99	100
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.02	4.15	4.19	4.09	4.16	4.26	4.28	4.05	4.04	4.09
% OF PREDICTED FEV-1	98	101	102	100	101	104	104	99	98	100
FEV-1/FVC, %	79	80	78	79	81	77	81	78	79	79
FEV-3/FVC, %	95	96	92	94	95	93	96	94	94	95
PEAK EXPIRATORY FLOW LT./MIN.	635	659	668	649	657	694	654	664	677	666
% OF PREDICTED PF	110	114	115	112	113	119	113	114	117	115
FORCED EXP. FLOW @ 50% OF FVC	271	290	268	275	277	272	342	274	292	277
FEF25-75% L/MIN	231	247	233	237	254	234	277	222	241	244
% OF PREDICTED FEF	92	98	92	94	102	92	109	88	95	96

APPENDIX A(30)

EXHIBIT 9

(Continued)

*** PULMONARY VALUES ***

NAME OF SUBJECT:
B5

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	4.92	5.21	5.76	5.76	5.33	5.49	5.63	5.19	5.26	5.24
% OF PREDICTED FVC	90	95	104	104	97	100	102	117	96	95
1-SEC FORCED EXPIRATORY VOLUME, LT.	3.94	4.26	4.85	4.88	4.47	4.61	4.62	4.22	4.38	4.26
% OF PREDICTED FEV-1	88	95	107	108	100	102	102	111	98	94
FEV-1/FVC, %	81	82	84	85	84	84	82	81	83	82
FEV-3/FVC, %	98	98	98	97	97	97	97	97	97	97
PEAK EXPIRATORY FLOW LT./MIN.	476	551	534	567	542	513	443	521	547	525
% OF PREDICTED PF	77	89	86	92	88	83	72	112	89	85
FORCED EXP. FLOW @ 50% OF FVC	268	336	376	327	321	336	358	317	303	330
FEF25-75% L/MIN	261	305	349	324	296	306	319	257	292	295
% OF PREDICTED FEF	89	104	118	110	101	104	108	102	100	100

*** PULMONARY VALUES ***

NAME OF SUBJECT:
B6

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.47	5.17	5.23	5.33	5.40	0.	5.24	5.22	5.28	5.19
% OF PREDICTED FVC	114	108	109	111	112	0	109	109	110	108
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.61	4.44	4.44	4.38	4.64	0.	4.59	4.66	4.41	4.22
% OF PREDICTED FEV-1	118	113	113	112	118	0	117	119	112	108
FEV-1/FVC, %	85	86	85	82	86	0	88	89	84	82
FEV-3/FVC, %	97	97	97	97	100	0	100	100	97	97
PEAK EXPIRATORY FLOW LT./MIN.	634	634	597	589	611	0	648	676	606	612
% OF PREDICTED PF	116	116	109	107	111	0	118	123	110	111
FORCED EXP. FLOW @ 50% OF FVC	336	331	327	289	389	0	351	348	332	326
FEF25-75% L/MIN	313	311	317	292	345	0	329	345	292	298
% OF PREDICTED FEF	120	119	121	112	132	0	126	132	112	114

*** PULMONARY VALUES ***

NAME OF SUBJECT:
B7

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	4.97	4.72	4.84	5.30	5.50	5.54	5.01	5.65	5.02	5.33
% OF PREDICTED FVC	98	93	95	129	108	109	99	111	99	130
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.14	3.81	4.11	4.30	4.49	4.49	4.09	4.71	4.02	4.47
% OF PREDICTED FEV-1	100	92	100	122	108	108	99	113	97	127
FEV-1/FVC. %	84	81	85	81	82	81	82	83	80	84
FEV-3/FVC. %	96	96	100	95	96	96	96	96	96	95
PEAK EXPIRATORY FLOW LT./MIN.	674	663	656	649	639	633	625	594	608	641
% OF PREDICTED PF	117	115	114	147	111	110	108	103	106	145
FORCED EXP. FLOW @ 50% OF FVC	362	274	361	355	356	389	333	347	323	376
FEF25-75% L/MIN	302	250	319	286	303	299	272	310	276	330
% OF PREDICTED FEF	112	93	118	123	112	111	101	114	102	141

*** PULMONARY VALUES ***

NAME OF SUBJECT:
M1

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	7.11	7.14	7.00	6.97	7.52	7.78	7.27	7.78	7.55	7.00
% OF PREOICTEO FVC	130	130	127	127	170	142	132	141	137	127
1-SEC FORCEO EXPIRATORY VOLUME, LT.	5.59	5.59	5.47	5.39	5.88	5.94	5.76	5.89	5.73	5.42
% OF PREDICTEO FEV-1	125	125	121	120	155	132	128	131	127	120
FEV-1/FVC, %	79	79	78	77	78	77	79	76	76	78
FEV-3/FVC, %	96	96	95	94	96	107	95	95	95	95
PEAK EXPIRATORY FLOW LT./MIN.	680	669	669	668	682	674	669	688	702	665
% OF PREDICTEO PF	111	109	109	108	146	110	109	112	114	108
FORCED EXP. FLOW @ 50% OF FVC	356	363	362	343	373	401	371	349	354	355
FEF25-75% L/MIN	316	319	311	296	337	331	340	318	309	311
% OF PREDICTEO FEF	108	110	107	101	134	113	116	109	106	106

*** PULMONARY VALUES ***

NAME OF SUBJECT:
M2

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.99	5.73	5.59	5.85	6.00	5.31	5.50	5.85	5.73	5.57
% OF PREDICTED FVC	111	106	103	108	111	98	101	108	105	103
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.51	4.37	4.10	4.32	4.24	3.98	3.96	4.15	4.21	4.03
% OF PREDICTED FEV-1	103	99	93	98	96	90	90	94	95	92
FEV-1/FVC, %	76	77	74	74	74	75	72	71	74	73
FEV-3/FVC, %	96	94	94	94	95	95	95	93	95	95
PEAK EXPIRATORY FLOW LT./MIN.	591	516	526	545	558	554	559	574	577	547
% OF PREDICTED PF	98	85	87	90	92	91	92	94	95	90
FORCED EXP. FLOW @ 50% OF FVC	250	318	227	234	205	228	210	213	271	204
FEF25-75% L/MIN	235	241	204	219	195	209	193	192	207	195
% OF PREDICTED FEF	83	85	72	77	69	74	68	68	73	69

*** PULMONARY VALUES ***

NAME OF SUBJECT:
M3

	SCREENING	BASELINE	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
FORCED VITAL CAPACITY, LT.	5.56	5.69	5.58	5.54	6.29	6.11	5.51	5.31	5.99	6.18
% OF PREDICTED FVC	108	110	108	108	122	118	107	103	116	120
1-SEC FORCED EXPIRATORY VOLUME, LT.	4.29	4.52	4.56	4.59	5.01	4.79	4.51	3.91	4.80	4.92
% OF PREDICTED FEV-1	102	107	108	109	118	113	107	93	113	116
FEV-1/FVC, %	78	80	82	83	80	79	82	74	80	80
FEV-3/FVC, %	98	97	100	0	97	97	97	100	98	98
PEAK EXPIRATORY FLOW LT./MIN.	528	641	625	660	670	678	657	638	658	713
% OF PREDICTED PF	91	110	107	113	114	116	112	109	112	122
FORCED EXP. FLOW @ 50% OF FVC	269	295	323	348	329	335	303	255	323	345
FEF25-75% L/MIN	245	263	290	304	297	294	282	232	290	292
% OF PREDICTED FEF	88	95	104	110	106	106	102	84	104	105

APPENDIX A(36)

EXHIBIT 10

Pollutant Concentration Data

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

B1

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	10.0	.9	6.2	8.4	7.7	8.4	12.0	13.0
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OZONE, PPB	125	80	80	22	22	200	65	45
NITRATES, UG/CM	0.	0.	0.	18.0	19.0	46.0	70.0	0.
SULFATES, UG/CM	0.	0.	0.	0.	0.	0.	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

EXHIBIT 10

(Continued)

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

B2	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	1.9	9.3	11.0	7.0	6.2	3.5	14.0	10.0
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	2.5	1.5	1.0	1.0
OZONE, PPB	30	70	85	65	95	92	100	40
NITRATES, UG/CM	0.	32.0	0.	0.	0.	23.0	0.	10.0
SULFATES, UG/CM	0.	21.0	0.	0.	0.	0.	0.	35.0

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

B3	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	11.0	4.0	0.	7.5	7.7	0.	7.0	21.0
CARBON MONOXIDE, PPM	1.0	1.0	0.	1.0	1.0	0.	2.5	1.0
OZONE, PPB	10	100	0	30	150	0	95	35
NITRATES, UG/CM	25.0	17.0	0.	0.	0.	0.	0.	0.
SULFATES, UG/CM	14.0	30.0	0.	0.	0.	0.	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

EXHIBIT 10

(Continued)

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

B4	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	14.0	6.8	10.0	2.7	6.8	5.2	9.5	2.7
CARBON MONOXIDE, PPM	1.0	1.0	1.0	2.0	1.0	1.0	1.0	1.0
OZONE, PPB	45	55	125	50	150	10	35	45
NITRATES, UG/CM	0.	0.	0.	4.0	0.	0.	0.	23.0
SULFATES, UG/CM	0.	0.	0.	0.	0.	0.	0.	31.0

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

B5	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	7.0	2.2	8.0	8.8	3.1	4.0	16.0	3.9
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	1.0	2.5	1.0	1.0
OZONE, PPB	75	65	80	100	20	65	45	45
NITRATES, UG/CM	0.	0.	18.0	27.0	0.	27.0	0.	0.
SULFATES, UG/CM	0.	0.	0.	0.	0.	0.	0.	33.0

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

EXHIBIT 10

(Continued)

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

B6

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	13.0	4.5	9.7	8.6	7.0	18.0	1.4	9.5
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	1.0	1.0	2.0	1.0
OZONE, PPB	40	150	70	85	30	65	10	35
NITRATES, UG/CM	0.	12.0	0.	0.	0.	10.0	63.0	0.
SULFATES, UG/CM	0.	0.	0.	15.0	0.	7.0	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT: B7

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	0.	15.0	9.7	6.2	2.7	18.0	0.	3.5
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	1.0	1.0	1.0	2.5
OZONE, PPB	35	80	200	65	50	65	30	65
NITRATES, UG/CM	0.	20.0	0.	22.0	0.	0.	0.	0.
SULFATES, UG/CM	0.	0.	0.	0.	0.	14.0	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

M1	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	10.0	7.0	1.8	7.0	11.0	18.0	14.0	13.0
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
OZONE, PPB	125	80	80	20	55	200	65	45
NITRATES, UG/CM	0.	0.	31.0	0.	7.7	24.0	37.0	21.0
SULFATES, UG/CM	0.	0.	0.	0.	0.	0.	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

APPENDIX A(44)

EXHIBIT 10

(Continued)

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

M2

	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	1.9	8.8	10.0	7.4	11.0	1.8	0.	15.0
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	2.5	1.5	1.0	1.0
OZONE, PPB	30	70	85	65	95	92	100	40
NITRATES, UG/CM	8.6	26.0	0.	0.	0.	0.	21.0	0.
SULFATES, UG/CM	0.	0.	0.	0.	0.	0.	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

EXHIBIT 10

(Continued)

POLLUTANT CONCENTRATIONS

NAME OF SUBJECT:

M3	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
CARBON MONOXIDE, PPM IN SITU	5.7	13.0	7.9	7.5	9.1	7.9	7.0	8.8
CARBON MONOXIDE, PPM	1.0	1.0	1.0	1.0	1.0	2.5	1.5	1.0
OZONE, PPB	10	20	40	30	150	95	92	35
NITRATES, UG/CM	0.	0.	0.	23.0	0.	9.6	0.	29.0
SULFATES, UG/CM	0.	0.	0.	0.	0.	0.	0.	0.

PPB- PARTS PER BILLION
PPM- PARTS PER MILLION
UG/CM- MICROGRAMS PER CUBIC METER

EXHIBIT 11

Meteorological Data

LOCAL METEOROLOGY

NAME OF SUBJECT	RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	RUN 8
B-1								
TEMPERATURE, F	90	90	92	74	90	92	82	96
RELATIVE HUMIDITY, %	60	50	60	55	67	60	62	60
B-2								
TEMPERATURE, F	74	83	81	92	98	96	95	83
RELATIVE HUMIDITY, %	27	46	42	60	56	60	60	70
B-3								
TEMPERATURE, F	72	97	0	84	87	104	0	82
RELATIVE HUMIDITY, %	90	54	0	60	55	46	0	62
B-4								
TEMPERATURE, F	94	90	90	83	85	74	82	91
RELATIVE HUMIDITY, %	60	63	60	32	67	85	39	30
B-5								
TEMPERATURE, F	90	93	95	99	74	95	96	81
RELATIVE HUMIDITY, %	40	62	52	60	55	65	60	30
B-6								
TEMPERATURE, F	79	84	85	80	84	92	92	92
RELATIVE HUMIDITY, %	70	55	46	42	60	50	67	39
B-7								
TEMPERATURE, F	82	95	92	93	83	92	72	97
RELATIVE HUMIDITY, %	39	59	60	62	32	50	25	56
M-1								
TEMPERATURE, F	91	89	95	74	90	92	82	96
RELATIVE HUMIDITY, %	60	49	60	55	67	60	62	60
M-2								
TEMPERATURE, F	74	83	81	92	98	96	95	95
RELATIVE HUMIDITY, %	27	46	42	60	56	60	60	85
M-3								
TEMPERATURE, F	72	80	87	84	85	104	95	82
RELATIVE HUMIDITY, %	80	71	41	66	67	46	60	62

APPENDIX B

TOTAL PARTICULATES DETERMINATION

Evaluation of total airborne particulate density for aggregates of diameter greater than 0.4 μm was done by a straightforward mass difference technique.

Each designated filter was weighed unused on a Sartorius electronic balance to determine the "clean" or "tare" weight. After exposure to ambient aerosol the filters were re-weighed on the same balance. The difference of the two masses was determined to be the mass of particulate matter on each filter.

To arrive at the density figure, the air volume of each exposure was calculated, and from this value concentration was derived:

$$(\text{Particulates}) = \frac{\text{Mass of Part., } \mu g}{\text{Air Volume, } m^3}$$

where μ denotes "the concentration of," μg is micrograms, m^3 is cubic meters.

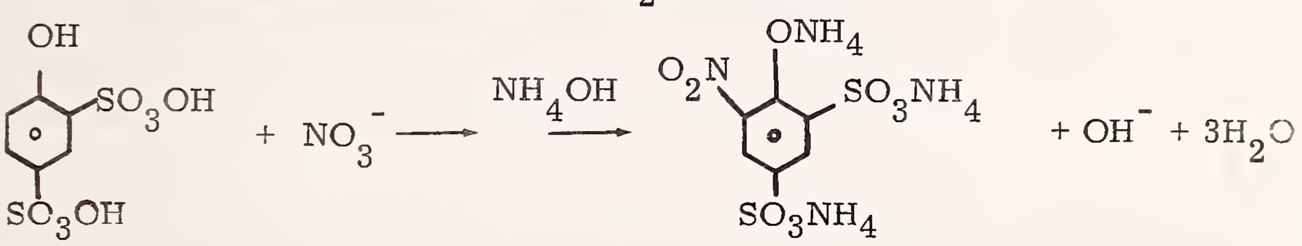
All weighings were carried out to the nearest 0.1 mg. Insufficient sample was collected on the filters due to the low flow rate of the pumps to permit reporting of accurate on-site particulates levels. Estimates of the mass of depositions on the filters range from .005-.025 mg.

APPENDIX C
COLORIMETRIC NITRATE ANALYSIS

This procedure determines the quantity of water-soluble nitrate species by measuring the intensity of color produced when a solution of nitrate ion is exposed to the reagent 2, 4-phenoldisulfonic acid (PDS, hence).

This type of analysis is well known, and has been used with few changes since the 1930's [34, 35, 36, 37].

The reaction occurs in an H_2O medium:



The formed species is yellow colored, and with good equipment as little as .05 $\mu g/ml$ can be detected at wavelength 410 nm. The reaction consists of two steps.

Initially, the cellulose acetate filters are stripped of their adhered nitrates by soaking in slightly acidic, warm, distilled water for about 30 minutes. The liquid is then transferred to the reaction vessel, and evaporated to dryness. H_2O_2 is added to ensure oxidation of any suspended organic matter. PDS reagent, freshly prepared (see footnotes for a more detailed description) is added, and color development allowed to progress for 10 minutes. Next, 10 percent NH_4OH (ammonia water)

is slowly added to each sample to intensify the color and complete the reaction. The contents of each reaction vessel are measured spectrophotometrically at 410 nm and absorbances compared to those corresponding to a similarly treated set of working standards, based on analytical reagent grade potassium nitrate (KNO_3).

APPENDIX D
TURBIDIMETRIC SULFATE ANALYSIS

Evaluation of suspended sulfates concentration was done by the widely used EPA-approved turbidimetric procedure. This procedure converts water soluble sulfate to the insoluble barium salt (ksp = 10^{-34}), which is suspended as a colloidal mixture and analyzed spectrometrically. The general reaction is:

$$XSO_4 \quad (aq) + BaCl_2 \xrightarrow{EtOH/Gly} BaSO_4(ag) + XCl$$

in which X is any positively charged ion, $BaCl_2$ is barium chloride, EtOH is absolute ethyl alcohol, gly is glycerol, SO_4 (aq) is aqueous sulfate, and (ag) denotes aggregated particles.

In practice, sulfate is extracted by allowing each filter to sit in warm, slightly acidic distilled water for at least 45 minutes. Then, the water plus sulfate is poured off and the filter discarded. The sulfate solution is then mixed with 4 ml of a 1:2 V/V glycerol/alcohol solution (colloidal stabilizer); as are a set of freshly prepared working standards (Na_2SO_4). Approximately 200 mg of $BaCl_2$ crystals are then added, which brings on the reaction. Full turbidity (cloudiness) requires a 40-minute equilibration period. The degree of light scattering, proportional to the concentration of sulfate, is then measured on a spectrophotometer (Spectronic 20) using light of wavelength 500 nm. To maintain uniformity of crystalline diameter, temperature is kept constant and uniform for all samples and standards, and pH is kept below 5.

All reagents used were of a good analytical grade or better.

APPENDIX E
CARBON MONOXIDE DETERMINATION

Determination of the concentrations of in situ carbon monoxide (CO) gas that motorists or bicyclists were exposed to was done by a grab sampling-NDIR (Non-Dispersive Infrared) EPA-approved technique. In this procedure, a quantity of air is pumped into a Tedlar bag for the duration of the exposure (one to two liters were taken to supply enough sample air to measure). Since this is an abnormally low sampling rate (relative to usual one-hour sampling rates), a specially controlled discontinuous sampler, the EMI Pulse-Pump[a] was used. This device operates for intervals of time (such as 2-8 sec off, 1 sec on) rather than continuously.

Filled bags were pinched shut, stored for not more than five days, and then analyzed on a Beckman 865 NDIR CO analyzer, using analyzed Linde-supplied CO gas as a reference. Output from the 865 was recorded on a strip chart, and the resulting graph was then converted to concentrations of CO.

(a) See "CO Sampling."

APPENDIX F

SPECTROPHOTOMETRIC DETERMINATION OF CARBOXYHEMOGLOBIN[38, 39]

PROCEDURES:

1. Place 25 ml of 0.4 percent NH_4OH into 35 ml test tubes marked reagent blank, quality control, and unknowns. Use prepipetter or equivalent.

2. Mix blood samples (Note 1) by inversion. Transfer 100 μl each of 40 percent CO quality control specimen and unknowns to previously marked test tubes. Use 100 μl MLA pipet or equivalent.

3. Cover the tubes with Parafilm, invert 3 times and allow to stand for 2 minutes or longer.

4. Place approximately 2.5 ml reagent blank in the reference cuvet. Add approximately 10 mg sodium hydrosulfite using a precalibrated scoop. Invert 10 times for thorough mixing.

5. Transfer approximately 2.5 ml 40 percent CO quality control solution to another cuvet. Add approximately 10 mg sodium hydrosulfite with precalibrated scoop and start timer. Invert 10 times for thorough mixing.

6. After 5-6 minutes, scan quality control solution vs. reagent blank from 650 nm to 500 nm using the Cary 15 Spectrophotometer (scan rate 150 nm/minute).

7. Remove quality control cuvet from instrument. Discard cuvet contents and proceed to next sample.

8. Prerinse cuvet with next sample and repeat steps 5 through 7 for each additional unknown (Note 2).

Note 1:

This procedure is valid only for unhemolyzed and undecomposed blood samples. If the blood does not appear normal, or if the absorbance reading of sample vs. reagent blank at 541 nm does not fall in the range of 0.2 to 0.5, a hemoglobin determination should be done and a calculated proportionate amount of blood used for CO determination:

$$\frac{15}{\text{gm Hb}/100\text{ ml}} = \frac{X}{100} \quad X = \mu l \text{ of blood used for analysis.}$$

Note 2:

If a number of samples are analyzed, the addition of sodium hydrosulfite is spaced so that each sample can be read between 5-6 minutes.

CALCULATIONS:

1. Obtain the absorbance at 541 nm and 555 nm for the 40 percent CO quality control specimen and each unknown from the chart recordings.

2. Calculate A541 nm/A555 nm for the 40 percent CO quality control specimen. It should be in the range of .955 - .995. If not, notify supervisor.

3. Calculate A541 nm/A555 nm for each unknown and obtain the percent CO saturation from the previously established calibration graph.

NORMAL RANGE:

In normal non-smoking individuals living in cities under conditions of minimal exposure to CO, 0.25 percent to 2.1 percent HbCO saturations have been found; normal tobacco smokers have HbCO saturations of 0.7 to 6.5 percent. Heavy smokers (more than 2 packs per day) may have as high as 8 to 9 percent saturation of hemoglobin with CO.

CLINICAL USEFULNESS:

Toxic symptoms, such as shortness of breath, begin to appear when the carboxyhemoglobin concentration is above 10 percent; values of 25 to 30 percent cause major symptoms of CO poisoning such as severe headache, irritation, fatigue and disturbance of judgment. Levels of 60 to 70 percent cause unconsciousness, respiratory failure and death if exposure is prolonged. Levels of 80 percent or above are rapidly fatal.

PRINCIPLE:

Hemoglobin and its derivatives have characteristic absorption bands in the visible region. Oxygenated hemoglobin and carboxyhemoglobin have closely situated double peaks in alkaline solution. The addition of sodium hydrosulfite to a weakly alkaline dilution of blood results in a significant change in absorption spectrum and absorption ratio at 541 nm/555 nm due to conversion of oxyhemoglobin (and any methemoglobin present) to reduced hemoglobin. Carboxyhemoglobin is unaffected by such treatment.

REAGENTS:

1. Ammonium Hydroxide: NH_4OH, 0.4 percent - approximately 16 ml of concentrated NH_4OH are diluted to one liter with deionized water. This solution is stable at room temperature.

2. Sodium Hydrosulfite (sodium dithionite) $Na_2S_2O_4$, Mallinckrodt

3. Carbon Monoxide Source - Lecture bottle Matheson Gas Products

4. Oxygen Source - Lecture bottle Matheson Gas Product.

EQUIPMENT:

1. 25 ml Prepipetter (or equivalent)

2. Cary 15 Spectrophotometer

3. 35 ml test tube (20 mm x 150 mm)

4. 100 μl MLA pipet (or equivalent).

PREPARATION OF 40 PERCENT CARBOXYHEMOGLOBIN QUALITY CONTROL

1. Twenty ml of oxalated blood (heparinized not stable even when frozen) are collected from a healthy non-smoker. Check Hb content for normality.

2. Transfer 10 ml of blood into each of two 125 ml separatory funnels. Add two drops of capryl alcohol to prevent frothing.

3. Slowly bubble pure oxygen through one sample of blood for 15 minutes. After addition of the gas, close separatory funnel and rotate gently by hand for an additional 15 minutes. This is the 0 percent CO specimen.

4. In a fume hood, slowly bubble pure carbon monoxide through the other blood sample for 15 minutes. After addition of the gas, close separatory funnel and rotate gently by hand for an additional 15 minutes. This is the 100 percent CO specimen.

5. Analyze each saturated sample according to the present procedure to establish the 0 and 100 percent carboxyhemoglobin calibration points. Compare with attached graph to verify values.

6. Slowly bubble nitrogen gas through the 100 percent carboxyhemoglobin sample for 1-2 minutes to remove any physically dissolved CO from the sample.

7. An intermediate quality control specimen of 40 percent is prepared by mixing 2 parts of the nitrogen treated sample (100 percent carboxyhemoglobin) with 3 parts oxygenated blood (0 percent carboxyhemoglobin).

8. The diluted blood sample is assayed for carboxyhemoglobin using the present procedure. An absorbance ratio of 0.975 - .995 should be obtained. If not, check with supervisor.

9. Place 2 ml aliquots of the control blood sample in 100 ml plastic vials (B-1) and freeze. Stable for 30 days.

QUALITY CONTROL:

Include the control described below with each run of unknowns and record results of the control on Q.C. chart prepared using the indicated limits. Label Q.C. chart with the identity of control material. Enter any "out of limits" condition on the "Out of Limits" log sheet, describing the cause of the problem and the action taken to correct it. Bring any such condition to the attention of the supervisor. Submit a daily summary on an "Out of Limits" report form to the Director or Assistant Director of the department.

Test each new lot of reagent concurrently with one of known acceptability before the new reagent is placed in routine use. Record the date of preparation and use check on the container label and record the introduction of a new reagent into routine use on the Q.C. chart or on a "New Reagents" log sheet to be kept with the Q.C. chart.

For emergency or research specimens, control specimen shall be employed to assure valid results.

Standard

No standard is available or necessary because test depends only upon the physical characteristics of the spectral absorption scan.

Control

a.	Composition	Carboxyhemoglobin in oxalated blood
b.	Concentration	40 percent
c.	Storage	Frozen; stable 30 days
d.	Instrument Used	Cary 15 Spectrophotometer
e.	Run Position	At the beginning of run
f.	Q.C. Chart	Absorbance ratio of $541_{nm}/555$ must fall between .955 - .995 values corresponding to 40 percent $\pm$ limits .975 $\pm$ .020.
g.	Reagent Check	Newly prepared ammonium hydro; solution evaluated along with presently acceptable NH_4OH using the 40 percent quality control specimen.

APPENDIX G

METHODOLOGY FOR THE DETERMINATION OF HIGH/LOW VOLUME ROUTES

1. ROUTE VOLUME DEFINITIONS

Determine from all traffic volume data in the area of interest, in this case the Washington, D. C., urban area, the highest and lowest traffic volumes on streets which typify those used in the study.

Develop high and low traffic volume criteria based on a partitioning of this range of values. For example, select the first quartile as low volume, and the last two quartiles as heavy and very heavy volumes, respectively.

For this study, a range of from 0 to approximately 6,000 vehicles per hour during the peak weekday evening rush hour period was observed. Therefore, the following breakdown is appropriate for this study:

Low volume	0-1,500 vehicles/hour
Medium volume	1,501-3,000 vehicles/hour
Heavy volume	3,001-4,500 vehicles/hour
Very heavy volume	4,501-6,000 vehicles/hour.

2. ROUTE VOLUME ANALYSIS

The criteria discussed above for low and high volumes, Exhibits 12, 13, 14, and 15 on pages G(3) through G(6) provide a summary of relevant traffic volume counts for the routes which were chosen as the best ones for the study from a large number of candidate routes. The route weight, or

fractional distance of a particular route segment compared to the entire route, is also listed with its corresponding count station and volume count. An average weighted volume was computed using these route weights by multiplying each of them by its corresponding traffic volume and summing this product for all route segments over the entire route. The equation for this process is as follows:

$$\sum_{i=1}^{M} W_i \; V_i$$

where W_i = Route weight for segment = $\dfrac{\text{Segment Length}}{\text{Total Route Length}}$

V_i = Volume for route segment $_i$

M = Total number of segments in a route

and $$\sum_{i}^{M} W_i = 1.00$$

It is readily apparent that the average weighted volume for each route is within the limits set for low and high volume for the respective low and high volume cases. Therefore, the criteria for route selection was met by these choices for Routes W, X, Y, and Z with:

Route	Average Weighted Volume [a]
Route W	3,128
Route X	4,532
Route Y	1,056
Route Z	1,340.

(a) Vehicles per hour.

APPENDIX G(3)

EXHIBIT 12

Route W—Route Volume Analysis

Intersection	Volume	Route Weight
21st and K Streets	3,670	.02
20th and K Streets	3,482	.04
18th and K Streets	2,621	.09
15th and K Streets	3,248	.02
14th and K Streets	4,236	.02
14th and L Streets	3,816	.17
Massachusetts and 18th Street	2,183	.10
New Hampshire and M Street	3,253	.10
21st and E Streets	2,448	.18
Constitution and 23rd Street	3,977	.17
23rd and F Streets	2,448	.09
		1.00

Average Weighted Volume: 3,128

APPENDIX G(4)

EXHIBIT 13

Route X—Route Volume Analysis

Intersection	Volume	Route Weight
Constitution and 23rd Street	3,977	0.05
Constitution and Henry Bacon Drive	4,422	0.20
Constitution and 17th Street	5,815	0.07
Constitution and 16th Street	3,213	0.07
Constitution and 15th Street	4,345	0.03
Constitution and 14th Street	5,022	0.10
Independence and 14th Street	5,104	0.01
Independence and 15th Street	3,519	0.13
Independence and 23rd Street	5,571	0.27
23rd Street and F Street	2,448	0.07
		1.00

Average Weighted Volume: 4,532

APPENDIX G(5)

EXHIBIT 14

Route Y—Route Volume Analysis

Intersection	Volume	Route Weight
14th and Madison Avenue	3,000	0.03
Jefferson Avenue and 12th	280	0.39
Madison Avenue and 7th	436	0.42
Constitution and 15th Street	3,519	0.000
Constitution and 16th Street	3,213	0.02
Constitution and 17th Street	5,815	0.02
Constitution and Henry Bacon Drive	4,422	0.04
Constitution and 23rd Street	3,977	0.02
23rd Street and F Street	2,448	0.06
		1.00

Average Weighted Volume: 1,056

APPENDIX G(6)

EXHIBIT 15

Route Z—Route Volume Analysis

Intersection	Volume	Route Weight
S Street and 18th Street	1,140	0.28
R Street and 18th Street	1,438	0.14
R Street and 19th Street	957	0.25
R Street and 21st Street	957	0.05
T Street and Florida Avenue	1,351	0.06
21st Street and P Street	1,111	0.07
21st Street and L Street	2,268	0.05
21st Street and F Street	2,448	0.02
Constitution and Henry Bacon Drive	4,422	0.00
Constitution and 23rd Street	3,977	0.01
23rd Street and F Street	2,448	0.07
		1.00

Average Weighted Volume: 1,340

APPENDIX H

METHODOLOGY FOR GRADE STRATIFICATION

Data from six subjects was analyzed to determine what percentage of total aerobic capacity (a measure of the quality of the cardio respiratory system) was expended in riding up a hill of a certain grade at a constant 7.5 miles per hour[26] (see Exhibit 16). Different subjects were used since aerobic capacity is not constant from one individual to the next. Fractions of aerobic capacity of 33 percent, 50 percent, and 90 percent can be used as fairly good measures of an acceptable level of work associated with bicycling up a grade. For each subject the grade was recorded at which he was expending the following fraction of aerobic work capacity:

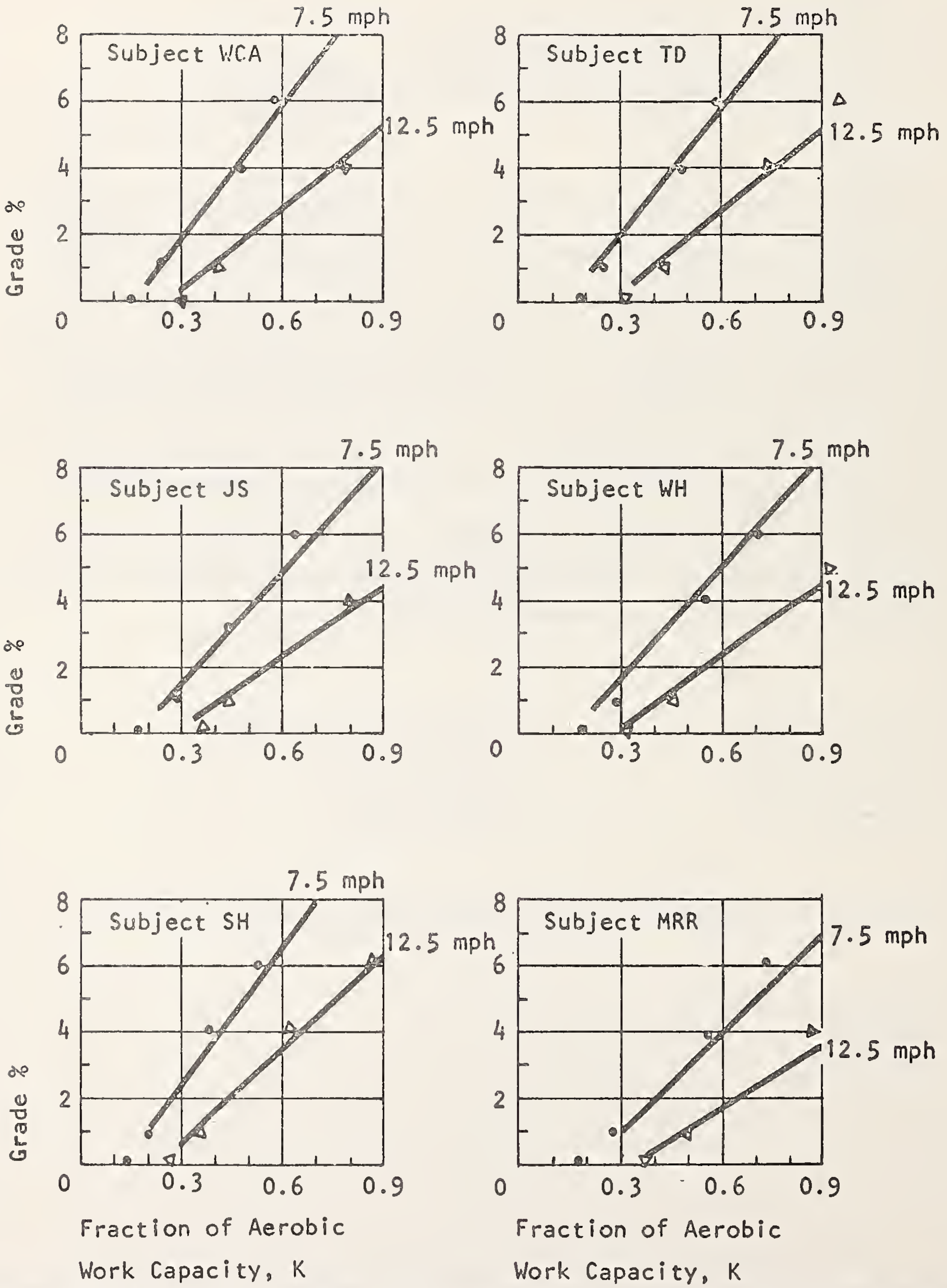
0.00 to 0.33	No grade to slight grade
0.34 to 0.50	Slight grade
0.51 to 0.90	Moderate grade
0.91 to 1.00	Heavy grade.

A table of this data is shown on page H(4)in Exhibit 17 for:

Subject i, $i = 1, 6$
Aerobic work capacity k, $k = 1, 2, 3$
Grade g_{ik}

EXHIBIT 16

Comparison: Measured to Predicted Grade-Work Relationship



Source: Smith, D.T., "Safety and Locational Criteria for Bicycle Facilities," FHWA-RD-75-112, Final Report, U.S. Department of Transportation, p. 181, 1976.

A calculation of the average grade for each fraction of aerobic capacity, 33 percent, 50 percent, and 90 percent, is made by summing each grade-subject combination for a particular aerobic capacity and dividing by the number of subjects. The equations are given by:

$$\frac{\sum_{i=1}^{6} g_{i1}}{6}, \quad \frac{\sum_{i=1}^{6} g_{i2}}{6}, \quad \frac{\sum_{i=1}^{6} g_{i3}}{6}$$

These average grades are given in Exhibit 18 on the next page.

From this data, the following stratification of grades are made:

No grade to slight grade	0.00 - 1.99%
Slight Grade	2.00 - 4.15%
Moderate Grade	4.16 - 8.99%
Heavy Grade	9.00 and above.

Exhibits 19, 20, 21 and 22, on pages H(5) through H(12), present the detailed grade analysis for Routes W, X, Y and Z, respectively.

EXHIBIT 17

Grades at Which Subject Experiences a Given Percent of Aerobic Work Capacity

SUBJECT	Fractional Aerobic Capacity @ 7.5 mph		
	$0.33_{k=1}$	$0.50_{k=2}$	$0.90_{k=3}$
$WCA_{i=1}$	2.0	4.5	10.0
$TD_{i=2}$	2.3	4.5	9.5
$IS_{i=3}$	1.8	3.8	8.1
$WH_{i=4}$	2.0	4.0	8.4
$SH_{i=5}$	2.6	5.1	10.8
$MRR_{i=6}$	1.2	3.0	6.8

EXHIBIT 18

Average Grades Relative to Aerobic Work Capacity

PERCENT	33	50	90
Average Grade	1.983	4.15	8.933
Rounded	2.0	4.15	9.0

Grades for Route W
(High Density/High Volume)

MAIN ROUTE

Rise/Run[(a)]	Grade[(b)]	Location
16/700	* 2.28	K St.
10/900	* 1.11	
18/1150	* 1.56	Vermont Ave.
6/500	* 1.20	Thomas Circle
2/200	* 1.00	
12/1200	1.00	Mass. Ave.
0/600	0.00	
11/100	* 1.10	
4/300	* 1.30	
2/600	* 0.33	DuPont Circle
2/600	0.33	
15/1025	1.46	New Hamp. Ave.
15/700	2.14	
5/825	* 0.60	

EXIT ROUTE

Rise/Run	Grade	Location
6/900	* 0.67	Pennsylvania Avenue
9/650	1.38	21st St.
0/450	0.00	
2/350	0.57	
35/200	1.75	
12/500	2.40	
1/1000	0.10	Constitution Avenue
32/575	* 5.56	23rd St.
14/800	1.75	
0/900	0.00	F St.
9/1025	0.87	22nd St.
16/725	* 2.20	

* Uphill

(a) Rise/Run in units of feet/feet
(b) Grade = (rise/run) x 100

ROUTE LENGTH ANALYSIS

Main Route x 2 Laps (9,400 x 2)	18,800 feet
Exit Route	8,075 feet
Total Length	26,875 feet

ROUTE GRADIENT ANALYSIS

GRADE	PERCENTAGE	DISTANCE (feet)
Downhill	43.1	11,575
None	46.9	12,600
Slight	7.9	2,125
Moderate	2.1	575
Heavy	0.0	0
	100.0	26,875 (5.09 mi.)

EXHIBIT 20

Grades for Route X
(High Volume/Low Density)

MAIN ROUTE

Rise/Run		Grade	Location
1/600	*	0.16	Constitution Ave.
1/1250		0.08	
4/1200		0.33	
5/925		0.54	
1/925		0.10	
0/500	*	0.00	
2/175		1.14	14th St.
15/700	*	2.14	
8/375	*	2.13	
3/600		0.50	Independence Ave.
5/200		2.50	
5/400		1.25	
6/650		0.92	
6/2350	*	0.25	
4/650	*	0.61	
7/400	*	1.75	Lincoln Memorial
0/1100	*	0.00	
7/600		1.16	23rd St.

13600 feet

EXIT ROUTE

Rise/Run		Grade	Location
32/575	*	5.56	23rd St.
14/800	*	1.75	
0/900	*	0.00	F St.
9/1025		0.87	22nd St.
16/725	*	2.20	

4025 feet

* Uphill

ROUTE LENGTH ANALYSIS

Main Route x 4 Laps (13,600 x 4)	54,400 feet
Exit Route	4,025 feet
Total Length	58,425 feet

ROUTE GRADIENT ANALYSIS

GRADE	PERCENTAGE	DISTANCE (feet)
Downhill	49.2	28,725
None	41.2	24,100
Slight	8.6	5,025
Moderate	1.0	575
Heavy	0.0	0
	100.0	58,425 (11.06 mi.)

APPENDIX H(9)

EXHIBIT 21

Grades for Route Y
(Low Volume/Low Density)

MAIN ROUTE

Rise/Run		Grade	Location
3/250	*	1.20	
5/200	*	2.50	
5/250	*	2.00	14th
5/150	*	3.30	
1/150	*	0.66	
8/400		2.00	Bike Path
1/400		0.25	
1/550		0.18	
3/1100		2.72	Jefferson Ave.
1/400		0.25	
15/2050		0.73	
1/1275		0.07	
1/1150	*	0.08	3rd St.
3/850	*	0.35	
6/600	*	1.00	
6/800	*	0.75	Madison Ave.
3/400	*	0.75	
1/575	*	0.17	
4/425		0.94	
2/150		1.33	14th St.

12125 feet

EXIT ROUTE

Rise/Run		Grade	Location
15/600		2.50	14th St.
0/500	*	0.00	
1/825	*	0.12	
4/2025	*	0.19	Constitution Ave.
1/1250	*	0.08	
1/600		0.16	
32/575	*	5.56	23rd St.
14/800	*	1.75	
0/900	*	0.00	F St.
9/1025		0.87	22nd St.
16/725	*	2.20	

9825 feet

* Uphill

ROUTE LENGTH ANALYSIS

Main Route x 4 Laps (12,125 x 4)	48,500 feet
Exit Route	9,825 feet
Total Length	58,325 feet

ROUTE GRADIENT ANALYSIS

GRADE	PERCENTAGE	DISTANCE (feet)
Downhill	50.2	29,225
None	43.5	25,400
Slight	5.4	3,125
Moderate	0.9	575
Heavy	0.0	0
	100.0	58,325 (11.05 mi.)

EXHIBIT 22

Grades for Route Z
(High Density/Low Volume)

MAIN ROUTE

Rise/Run		Grade	Location
10/500		1.00	T St.
4/250		1.60	18th St.
6/500	*	1.20	Swann St.
5/275		1.81	19th St.
5/500		1.00	S St.
4/350		1.14	18th St.
8/900	*	0.88	R St.
6/550	*	1.09	20th St.
12/350	*	3.42	20th St.
0/350	*	0.00	Florida Ave.
4/150		2.66	T St.
4675 feet			

EXIT ROUTE

Rise/Run		Grade	Location
4/400		1.00	R St.
9/700		1.28	
4/350		1.14	
28/2200		1.27	
4/250	*	1.60	21st
5/150	*	3.33	St.
5/175	*	2.85	
10/200	*	5.00	
2/125	*	1.60	
9/900		1.00	
49/3050		1.60	
1/1000		0.10	Constitution
32/575	*	5.56	23rd St.
14/800	*	1.75	
0/900	*	0.00	F St.
9/1025		0.87	22nd St.
16/725	*	2.20	
13525 feet			

* Uphill

ROUTE LENGTH ANALYSIS

Main Route x 10 Laps (4,675 x 10)	46,750 feet
Exit Route	13,525 feet
Total Length	60,275 feet

ROUTE GRADIENT ANALYSIS

GRADE	PERCENTAGE	DISTANCE (feet)
Downhill	49.7	29,875
None	41.6	25,075
Slight	7.5	4,550
Moderate	1.2	775
Heavy	0.0	0
	100.0	60,275 (11.42 mi.)

APPENDIX I

DESCRIPTION OF SELECTED COMMUTER ROUTES

1. ROUTE W

Route W is designated as the high volume/high density course. A map showing the location of this route is presented as Exhibit 23 on page I(6). The total one-hour course is 5.09 miles long, and because it has the highest concentration of traffic and traffic control signals, 30 minutes are required to complete one lap and an exit to the Medical Center. Two laps around the main course, plus the exit route, required approximately one hour of travel time for both bicyclists and motorists.

The circuit starts at the east side of Washington Circle and K Street. The subjects proceed east along K, accessing the main fraction of the street at 20th Street. They continue proceeding to Vermont Avenue, N.W., where they execute a left turn. Vermont Avenue feeds into Thomas Circle: the subjects navigate around this zone to the Massachusetts Avenue turnoff. They continue on a straight course, now along Massachusetts Avenue, past Scott Circle to DuPont Circle. At DuPont, they take the New Hampshire Avenue (Route 29) south exit, and follow that to the detour at M Street.

The detour forces all traffic to bear right on M Street. At 23rd Street, the subjects turn left and are led into Washington Circle where they complete their circuit.

An exit route for this circuit was devised to obtain the needed hill requirement for approximately 1 percent of each course. To gain access to the exit route, the subjects, if in the 30-minute duration test, engage Pennsylvania Avenue east off the Circle, which connects with 21st Street. At 21st Street, a right turn is taken, and the road is followed south all the way to Constitution Avenue. At Constitution a right turn is needed to proceed in the proper direction to the exit route.

This circuit is heavily used during rush hour and is densely populated with tall buildings. Refer to Exhibit 23 for a map of Route W.

2. ROUTE X

Route X is designated as a high volume/low density circuit, 11.06 miles long for the bicyclist engaging in a one-hour ride.

A map showing the location of Route X is presented as Exhibit 24 on page I(7).

Motorists start at Henry Bacon Drive and Constitution Avenue, N.W., north of the Lincoln Memorial. They drive east towards 14th Street, turning right there and then turning right again onto Independence Avenue just past the Sylvan Theatre. Independence is taken west past the Lincoln Memorial, under the Arlington and Rock Creek overpasses to the E Street expressway, whereupon the motorists bear east to Virginia Avenue (via D Street). They use Virginia Avenue to access 21st Street South, which flows into Constitution Avenue just east of the starting point.

The bicyclists' route originates identically. Bicyclists follow the motorists' circuit all the way to the intersection of the Lincoln Memorial with Independence Avenue, where they bear right. They ride up to and

east of the Memorial overlooking the Reflecting Pool to Bacon Drive, which they take back to Constitution Avenue and resume the circuit again.

After a sufficient number of laps have been accomplished (two laps are necessary per 30 minutes of bicycling) all subjects exit off the main circuit at Bacon and Constitution Avenues (bicyclists) or 21st and Constitution Avenues (motorists) by proceeding west on Constitution towards 23rd Street, where a right turn is made onto a moderately graded hill to the Medical Center via the exit route.

This circuit, excepting the exit route, borders primarily on the Lincoln Memorial, Reflecting Pool, and Washington Monument grounds and is heavily used during rush hours.

3. ROUTE Y

Route Y, the Mall route, is designated as low volume/low density. It covers 2.29 miles in its cyclic portion and is traversed twice in a 30-minute test (four times in an hour's test) by a bicyclist, for a total route length of 11.05 miles, including exit route.

A map showing the location of Route Y is presented as Exhibit 25 on page I(8).

The route initiates at 14th Street, N.W., at the Museum of History and Technology.

Fourteenth Street is taken south almost to Independence Avenue, where just before intersecting the bicyclist turns right onto a bike path, loops

around, and then re-enters 14th, crossing it to Jefferson Drive, which is followed past several museums and art galleries to 3rd Street. Rather than turning on to 3rd, the bicyclist makes a left onto the sandy path bordering 3rd, cutting across the Mall to Madison Drive, which he takes westward back to 14th Street, the starting point of the trip.

A motorist uses the identical rectangular format, with the exceptions that he will turn left at Jefferson immediately upon encountering it, and also turns left onto 3rd Street.

Both sets of subjects leave the circuit by turning right onto 15th Street, going north to Constitution Avenue, then turning left and bearing toward 23rd Street, where the exit route is taken.

This route is used very little by motorists, even during rush hour, and is characterized by slow moving traffic and open spaces.

4. ROUTE Z

Route Z, the residential route, represents the low volume, high building density case. It is located north of DuPont Circle, in a quiet, fairly flat zone of town. The total length for a one-hour ride (bicyclist) is 11.42 miles. A map showing the location of Route Z is presented as Exhibit 26 on page I(9).

All subjects start at the corner of R and 18th Streets, proceeding westerly past a row of houses (typical for the entire route) to 20th Street, a one-way north route. They take 20th to Florida Avenue, whereupon the course is directed easterly to T Street. (Although Florida Avenue is heavily used during rush hour, it is a part of the course for less than 150 feet.) T Street is taken to 18th Street, about four blocks north of the starting point. Subjects turn right onto 18th Street then right again at the end of the block onto Swann Street. At the end of Swann, a left

turn onto 19th Street is made, and again at the end of the block, a left turn is made to get onto S Street. S Street is taken for one block back to 18th Street, a right turn is executed, and the subjects then return to the starting point at R and 18th Streets, bypassing Riggs Place, which is one way in the opposing direction (thus excluding motorists' entry). Swann, and S and T Streets are similar to R Street in that each is lined with attached housing units approximately three stories tall. For the most part, these are narrow, minimally utilized streets.

The course is a circular zig-zag, and is calculated to require five laps of 12 miles per hour cycling in order to complete a 30-minute run (see page I(9)). Included in this figure (as in all the other ones) is the time required to return to the Medical Center. The return path routes the subjects westerly on R across Connecticut Avenue to 21st Street south (one way). 21st Street terminates at Constitution Avenue, where a right turn is made, and then one and half blocks later, another right is executed to bring the subjects to 23rd Street north, and the exit route.

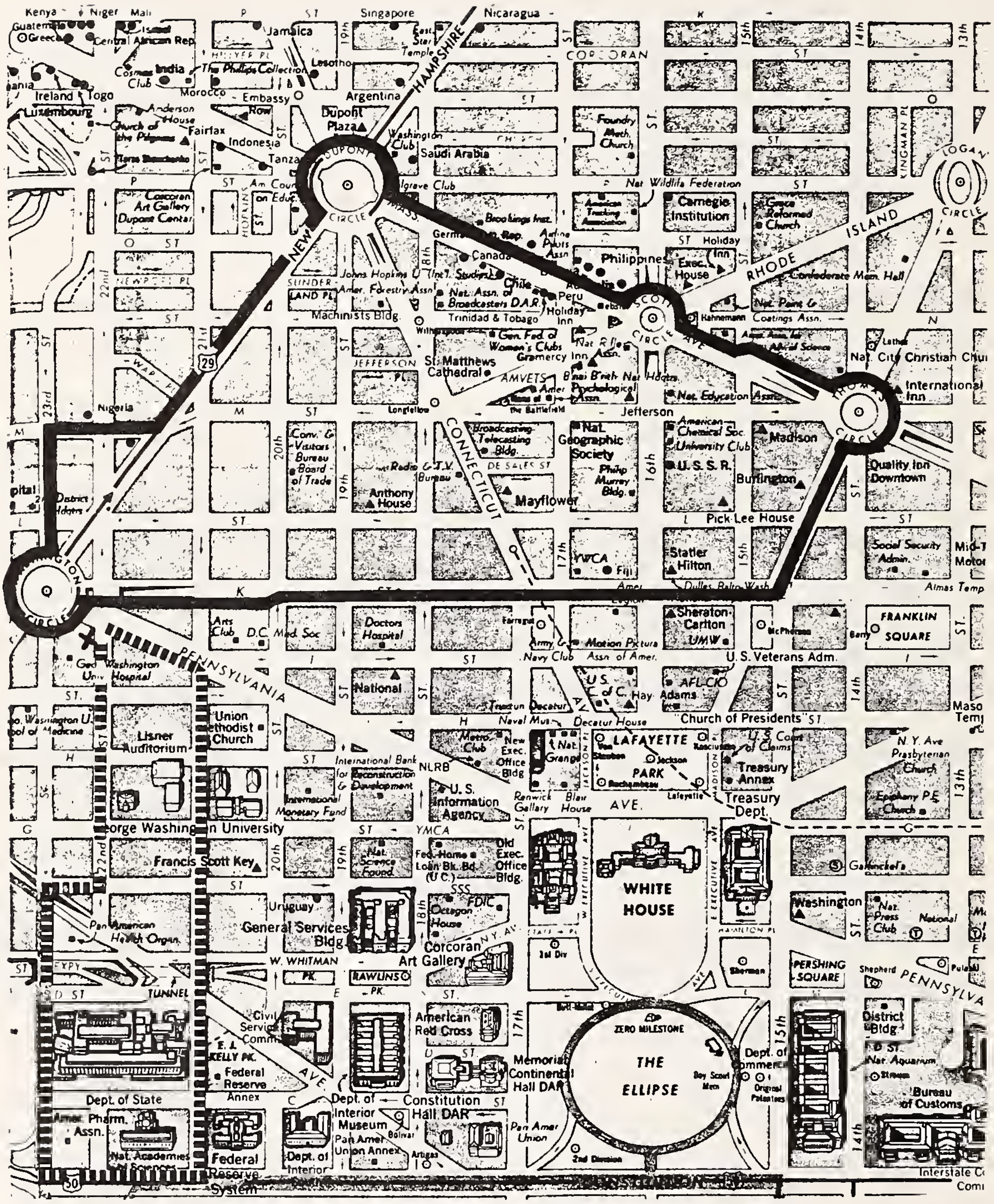
21st Street conforms to the general layout of Route Z, as it is mainly comprised of apartment buildings and townhouses spaced closely for long stretches.

5. EXIT ROUTE

This was devised for Routes W, X, Y, and Z in order to include a hill of moderate grade for 1 percent of the total path. It starts at 23rd and Constitution. Subjects travel up (north) along the hill on 23rd to F Street, where they go right, then left a block later onto 22nd Street, which they take for four blocks north to the Medical Center's entrance. The diversion is included because north of F Street, 23rd is one-way south.

EXHIBIT 23

Route W



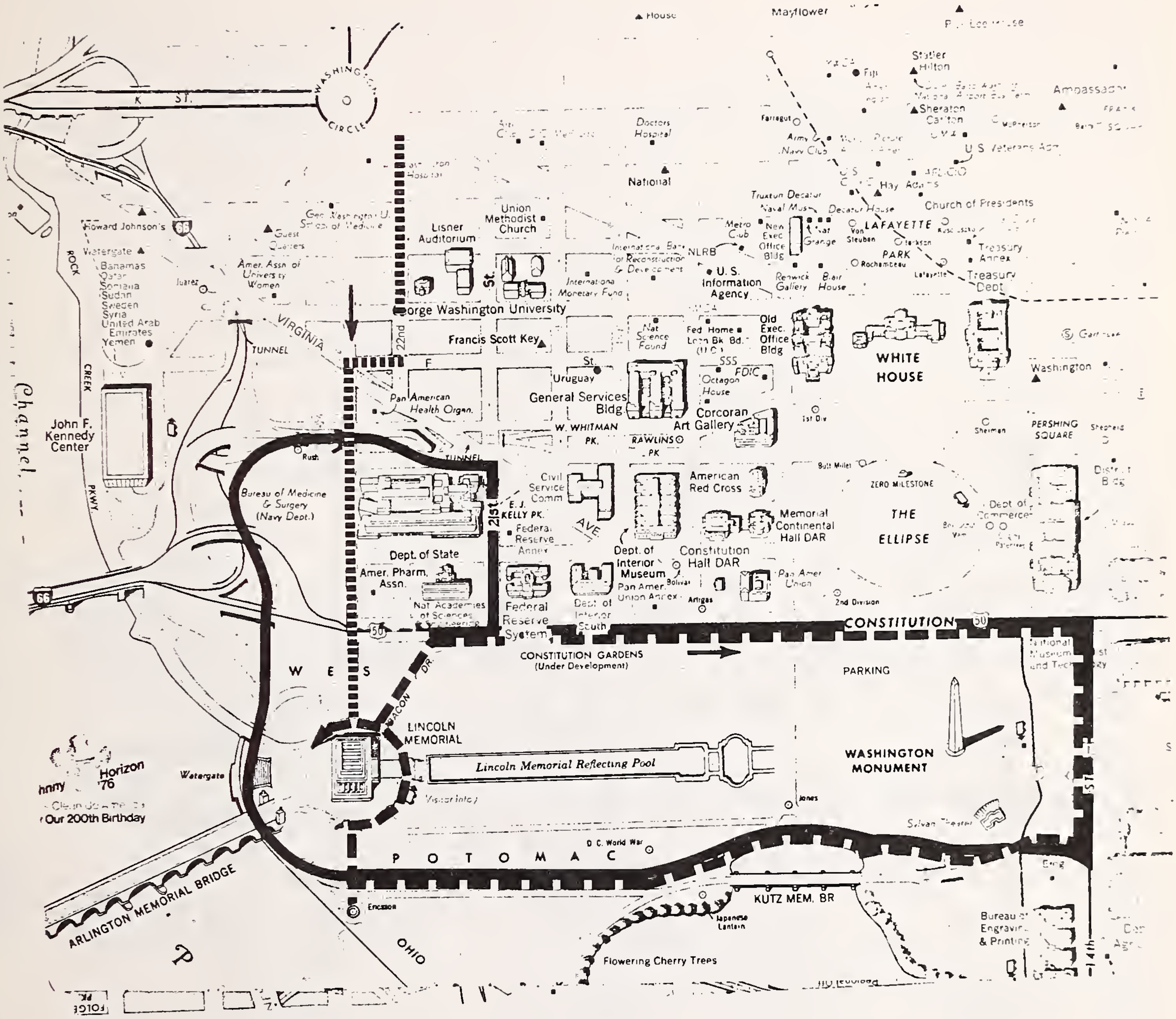
LEGEND:

Exit route

Main course

EXHIBIT 24

Route X



LEGEND:

▮▮▮▮▮▮▮▮	Exit route
▬ ▬ ▬ ▬	Main course, bicyclists
▬▬▬▬	Main course, motorists

EXHIBIT 25

Route Y

LEGEND:

Exit route

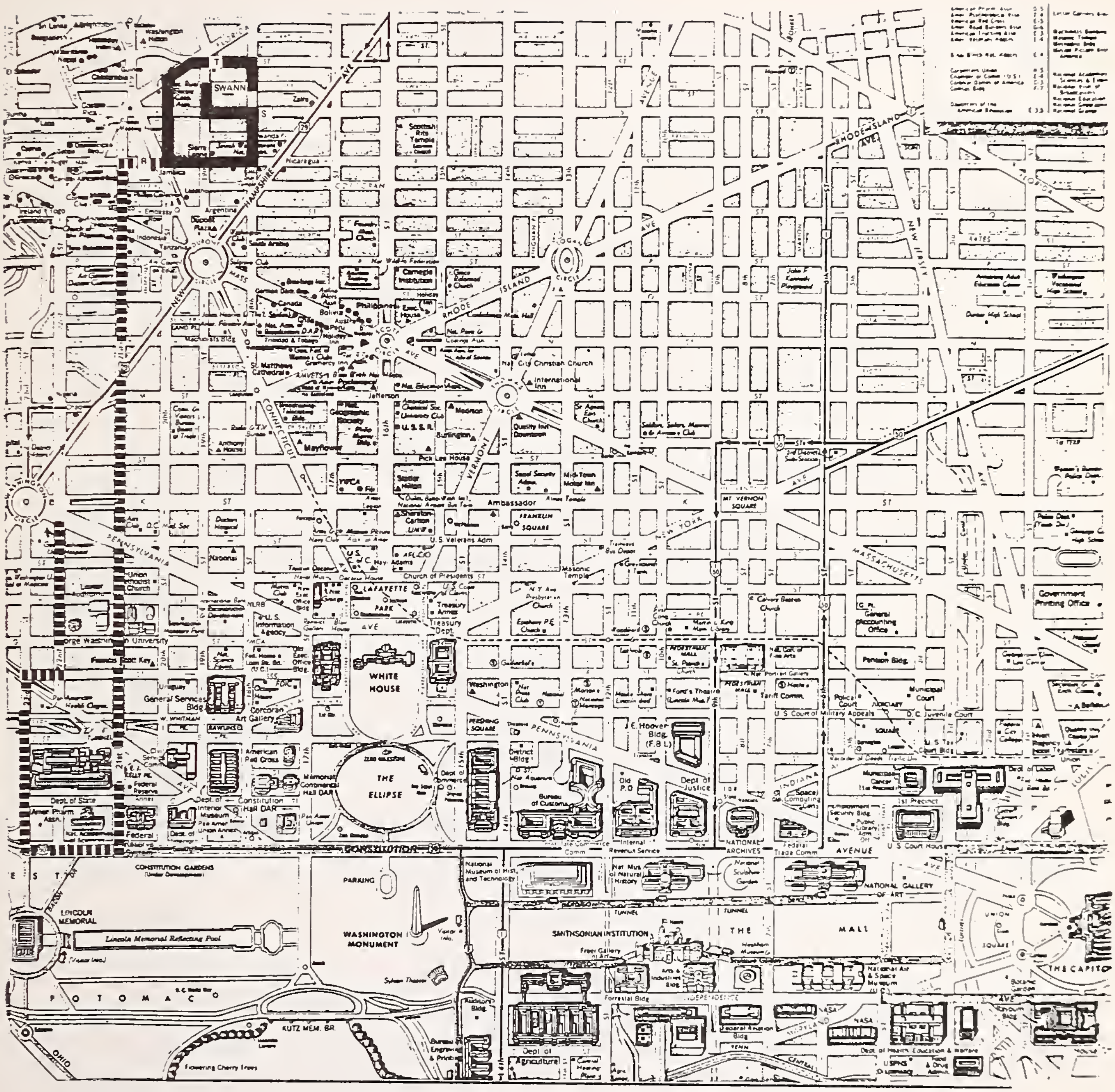
Main course, bicyclists

Main course, motorists

APPENDIX I(9)

EXHIBIT 26

Route Z



LEGEND:

Exit route

Main course

APPENDIX J

DESCRIPTION OF THE BICYCLES AND AUTOMOBILE

Two Motobecane "Super Mirage" ten-speed bicycles with 27" hub wheels were purchased for this study. They were equipped with flexible-pole flags (for visibility), reflectors, front racks, baskets (for the CO monitoring equipment and instruction cards), speedometers and "toe clips." Their frame sizes were 23" and 25", to accommodate two different height ranges of riders (5'7" to 6'2" altogether).

Heavy-gauge stranded wire cable plus integrated key-operated locks were purchased for securing the bicycles when not needed, carrier racks for transportation of the bicycles, and lightweight helmets for the bicyclists' protection.

Throughout the period May 26 to July 22, the same 1976 Plymouth Valiant four-door automobile was leased from a rental company for use as the motorists' automobile. A preliminary check of the interior of the car was performed to test for background levels of CO (from exhaust system leaks), but no concentrations above those of the ambient air could be detected.

The car was chosen to typify a commuter's vehicle. It came with power steering, automatic transmission, and a six-cylinder engine with standard emission controls.

During the tests, the forward windows were kept rolled down to expose the driver to the same ambient aerosol as the accompanying bicyclist, and each driver was asked not to use the air conditioning. The car was left in a George Washington University parking lot when it was not needed.

APPENDIX K

DESCRIPTION OF THE MAXIMAL MULTI-STAGE TREADMILL TEST

Maximal multi-stage treadmill testing was performed at the George Washington University Medical Center exercise laboratory which is equipped with a treadmill (Quinton Model 18-49C) with variable belt speed and bed slope, a single channel ECG recorder, an oscilloscope, sphygmomanometer, and a DC defibrillator (American Optical Corporation Model #10645F). Informed consent for testing was first obtained, and the principles of the test explained. The subject was given a cardiovascular examination by a physician trained in clinical exercise testing, who also directly supervised the test.

A resting 12 lead ECG was obtained first. The exercise ECG was obtained from lead CM_5 (1) bipolar lead with electrodes placed on the manubrium of the sternum and the V_5 position. The ECG was monitored continuously on an oscilloscope and a five-second recording made every minute of exercise and recovery. (Additional recording may be performed if clinically indicated and at peak exercise.)

The blood pressure was recorded at rest, during the third minute of each stage, and during the fifth minute of recovery after maximal exercise. The treadmill speed and grade was increased every three minutes according to the Bruce Protocol (Table 23). Exercise was terminated as soon as the subject indicated he could go no further, and the duration of exercise recorded. Careful watch was made for abnormal responses, but no clinically significant abnormalities that would require stopping the treadmill test were observed.

TABLE 23

The Bruce Protocol

Stage	Speed	Grade	Minutes	Approximate O_2 Cost [(a)]	METS [(b)]
Rest	0	0	0	3.5 - 4.0	1
I	1.7 mph	10%	3	17	5
II	2.5 mph	12%	6	25	7
III	3.4 mph	14%	9	34	10
IV	4.2 mph	16%	12	44	13
V	5.0 mph	18%	15	56	16

(a) ml O_2/kg body wt/min (men)

(b) METS: (Metabolic units): multiples of resting O_2 consumption (approximate).

APPENDIX L

DESCRIPTION OF THE PREDICTIVE PULMONARY SCREENER

Tests of pulmonary function were performed at the George Washington University Medical Center, Pulmonary Function Laboratory, which is staffed by trained pulmonary function technicians.

Ventilation testing was performed with a "Predictive Pulmonary Screener[a]" (see Exhibit 27) to determine the Forced Vital Capacity (FVC), the Forced Expiratory Volume at 1 second (FEV_1), the Forced Expiratory Volume at 3 seconds (FEV_3), the Peak Flow (PF), the Forced Expiratory Flow at 50 percent of Forced Vital Capacity (FEF_{50}), and the Forced Expiratory Flow at 25-75 percent ($FEF_{25-75\%}$).

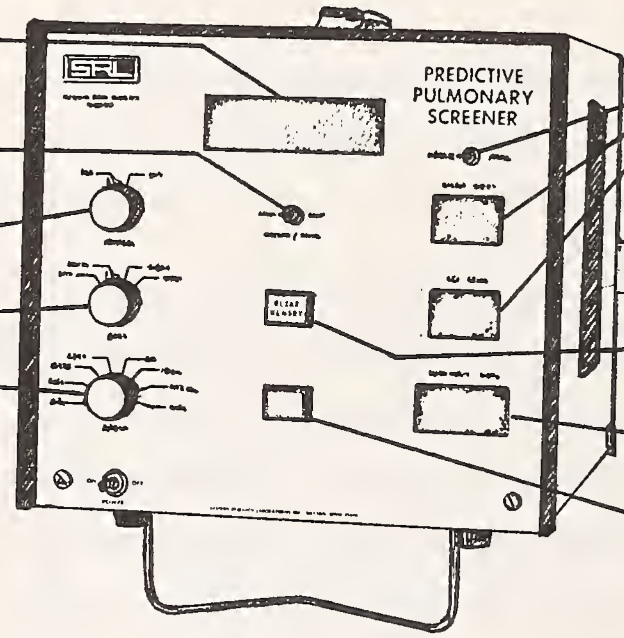
By dialing in the subject's age, sex, and height, performance could also be expressed as a percentage of the predicted value based on the norms developed by Korey[40] and Morris[41]. Temperature and pressure corrections were made by entry of the local barometric pressure and the screener converted all readings to BTPS. The screener automatically stored the values of three forced expirations and selected the best of the three attempts for printing.

(a) Systems Research Laboratories, Inc., Dayton, Ohio.

EXHIBIT 27

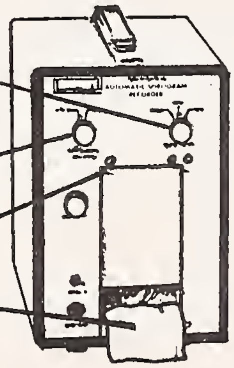
Predictive Pulmonary Screener

Predictive Pulmonary Screener

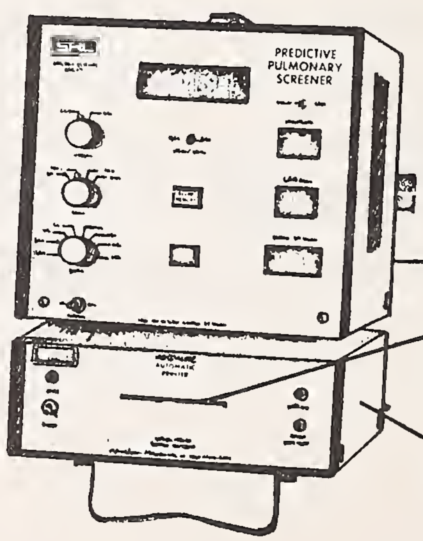


Accessory Equipment

ALL ACCESSORIES AND OPTIONS EASILY ADDED – NO FIELD INSTALLATION OR FACTORY RETURN NECESSARY.



Automatic Spirogram Recorder



Automatic Card or Roll Printer

APPENDIX M

LETTER—GENERAL INFORMATION FOR SUBJECTS

May 17, 1977

Thank you for agreeing to participate in this study entitled "Health Effects of Bicycling in a Polluted Environment." We are very excited about this project and feel that this is a real opportunity to do some testing in the actual environment in which all of us ride. Because we have such a small number of subjects for this initial effort (10) we are really counting on the cooperation, endurance and enthusiasm of each one of you to complete your entire series of eight runs.

MEETING

A meeting of all subjects is scheduled for May 19 at 5:30 P.M. at the George Washington University Hospital, Room 2363 (use 22nd Street entrance). The entire study will be reviewed at that time and any questions answered. Equipment will be presented and demonstrated. Papers for insurance coverage will also need to be signed at that time. If you are unable to attend this meeting, please call me by phone (589-5955) so that we can make other arrangements for getting your signature and answering questions. We also feel that it would be interesting for each of you to meet each other, as this is the only time during the study that all subjects will be together.

SCHEDULES

We have finally received the remainder of our air monitoring equipment and plan to run the testing May 23 through July 11 (five days a week), excluding the Memorial Day holiday and July 4th holiday. Make-up days have been scheduled for July 12-22 as needed. The decision to cancel a run (due to rain, heat or winds) will be made by 2:00 P.M. on each testing day and you will be notified by phone of cancellation at that time.

May 17, 1977
Page Two

We will plan to call each one of you weekly to confirm your schedule for the following week, and also will be in touch with you on the night before testing as a reminder. Your individual schedule for the eight test runs is clipped to this letter. We have taken into consideration any vacation or off time that you have indicated to us. If you anticipate any further problems in being unable to fulfill your schedule on the dates indicated, please contact us immediately so that other arrangements can be made.

We will be making further arrangements for pick-up locations and times on an individual basis by phone. Transportation after testing will be provided to the destination of your choice.

CLOTHING

In order to equalize any variables concerning clothes, we request that each of you wear a pair of shorts, T-shirt, belt (to clip monitoring equipment to) socks, and shoes that will provide good traction (bicycle shoes, sneakers, running shoes, etc. —no street shoes).

DIET ON DAY OF TESTING

On the day of testing, Dr. Gorman requests that you restrict all caffeine intake (coffee, tea, cola) after 9:00 A.M. and that your lunch menu be light—a sandwich and fruit juice is suggested. Be sure to keep up your fluid intake. Fluids will be available at the lab following the testing.

ROUTES

The routes have been selected to illustrate four different types of environments in the D.C. area, and differ in traffic volume and building density.

You will ride each of these routes twice, once for 30 minutes, and once for 60 minutes. The routes are all equal in exertion levels and all have been designed to end at George Washington University Hospital. Maps and route descriptions are included in this letter.

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We encourage you to practice the routes if they are unfamiliar to you to enhance your own safety during the run. We have tried to make the routes as uncomplicated as possible, yet at the same time fulfilling the necessary criteria for the project. All bicyclists are instructed to ride at 12 miles per hour and motorists to travel at the posted speed limits.

INSURANCE

For the purpose of this study, you will be considered part-time employees of this firm which makes you eligible for Workman's Compensation. An additional insurance policy has also been obtained, the details of which will be covered at the meeting. We will also need you to complete some insurance papers at that time.

PAYMENT AND DISCUSSION OF RESULTS

At the completion of your eight run series, you will be paid $80. An appointment with Dr. Gorman will also be arranged to discuss the results of your physiological testing. No discussions of results will take place during the testing due to the nature of the study design. We will also arrange for you to receive copies of the final report when the study is finished.

* * * * *

I am looking forward to seeing you at the meeting.

Sincerely,

MESSER ASSOCIATES, INC.

Sharlene Weiss
Project Manager

Enclosures

jeb

APPENDIX N

HEALTH EFFECTS SUMMARY OF AIR POLLUTANTS MEASURED IN THIS STUDY[a]

Pollutant	Characteristics	Principal Sources	Health Effects
Carbon Monoxide (CO)	Odorless, invisible gas; readily absorbed in the blood stream by hemoglobin	Internal combustion engine exhausts, forest fires, decomposition of organic matter	Reduced exercise endurance, impairment of nervous system function, aggravation of cardiovascular diseases, impairment of fetal development
Photochemical Oxidants (including Ozone)	Invisible gases, most of which have strong, irritating odors	Found in photochemical smog as reaction products from chemical precursors exposed to sunlight	Irritation of mucous membranes, aggravation of respiratory and cardiovascular illnesses, reduced exercise endurance
Sulfates (SO_4)	Sulfur oxides formed aerosol, sometimes taking the form of a sulfuric acid mist	Atmospheric reactions of sulfur oxide precursors	Aggravation of respiratory diseases, irritation of mucous membranes
Nitrates (NO_3)	Nitrogen oxides formed aerosol, sometimes taking the form of a nitric acid mist	Atmospheric reactions of nitrogen oxide precursors	Aggravation of respiratory and cardiovascular diseases and chronic nephritis

(a) Source: Environmental Quality, the Sixth Annual Report of the Council on Environmental Quality, pp. 301, 302, 328, December 1975

APPENDIX O
STATISTICAL ANALYSIS TECHNIQUES

The following topics are discussed in this appendix:

- Simple (bivariate) regression analysis
- Multiple regression analysis
- Crosstabulation analysis (χ^2 test of independence).

1. SIMPLE (BIVARIATE) REGRESSION ANALYSIS

Simple regression analysis refers to the general situation of relating the values of a single dependent or predicted variable (Y) to the values of a single independent, or predictor variable (X). The aim of this process is the prediction of Y values from X values. The most common type of regression is linear regression in which the object is to find the "best fitting" straight line. The general formula for a straight line is:

$$Y = a + bX,$$

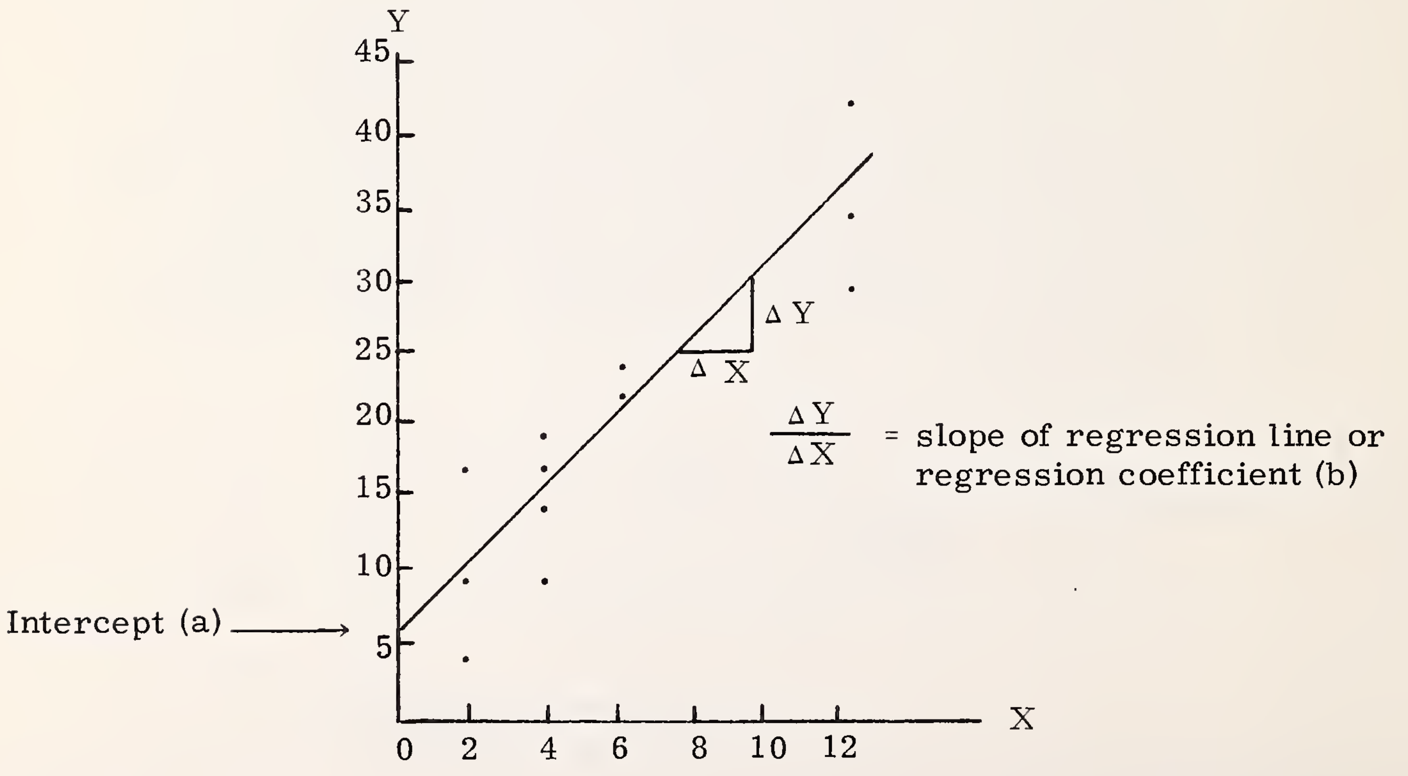
where

a = Y intercept

b = slope of regression line or regression coefficient.

The most common statistical procedure for determining a straight line given paired observations of the dependent and independent variables is called least-squares regression. The least squares regression line is that in which the vertical distances of all the paired observations from the line are minimized (i.e., the sum of squares of vertical deviations from this line is smaller than the corresponding sum of squares of deviations from any other lines) and is the "best-fitting" line for a given set of paired observations. The output consists of the best, linear, unbiased estimates of the slope and intercept.

An illustration of an estimated regression line in relation to paired observations of the dependent variable Y and the independent variable X is shown below.



In simple regression analysis, the hypothesis that variable Y is independent of variable X is frequently tested. This is accomplished by making the hypothesis that the regression coefficient (b) is equal to zero, and that Y is not dependent upon X. Student's t test is then used to test this hypothesis. In the cast of simple regression analysis, the t statistic is:

$$t = \frac{(b-0)\, s_x \sqrt{N-1}}{s_{y.x}}$$

where

b = regression coefficient

s_x = standard deviation of X

$s_{y.x}$ = standard error of estimate of Y

N = number of observations

For a given number of observations, the higher the absolute value of the calculated t statistic, the more likely that b is not equal to zero and that Y is, in fact, dependent upon X. By comparing the calculated t statistic with a table of percentiles of the t distribution, the acceptance or rejection of the hypothesis that $b=0$ can be made at a certain level of statistical significance (e.g., 95 percent).

2. MULTIPLE REGRESSION ANALYSIS

The multiple linear regression equation and the basics of it are a straight extension of the bivariate case previously discussed. The prime difference is the use of a larger group of independent variables that produce an equation of the following form:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + \ldots\ldots + b_k X_k.$$

The number of independent variables included can be any number desired or can be decided during computation on the basis of some selected criteria. As it can be seen, there is still only a single value of the Y-intercept but there is a regression coefficient, b, for each independent variable that is in the equation.

In multiple regression analysis, the hypothesis that variable Y is independent of variables $X_1, X_2, X_3, \ldots\ldots X_k$ is frequently tested. This is accomplished by making the hypotheses that the coefficient of multiple determination (R^2) is equal to zero and that all the regression coefficients (b_1, b_2, b_3, ...b_k) are equal to zero and that Y is not dependent upon X_1, X_2, X_3, ...X_k. The F test is then used to test the hypothesis. In the case of multiple regression analysis, the F statistic is:

$$F = \frac{R^2/k}{(1-R^2)/(N-k-1)},$$

where R^2 = coefficient of multiple determination

k = number of independent variables

N = number of observations

For a given number of observations, the higher the value of the calculated F value, the more likely that R^2 is not equal to zero, that all the regression coefficients are not equal to zero, and that Y is, in fact, dependent upon $X_1, X_2, X_3, \ldots\ldots X_k$. By comparing the calculated F statistic with a table of percentiles of the F distribution, the acceptance or rejection of the hypotheses that $R^2=0$ and that $b_1 = b_2 = b_3 \ldots\ldots b_k = 0$ can be made at a certain level of statistical significance (e.g., 95 percent).

3. CROSSTABULATION ANALYSIS (χ^2 TEST OF INDEPENDENCE)

Crosstabulation analysis is used to help determine whether or not a systematic relationship exists between two or more variables. A crosstabulation is defined as a joint frequency distribution of two or more classificatory variables. An example of a crosstabulation is shown below:

		NITRATES DETECTED	NITRATES NONDETECTED	
FATIGUE	YES	5	21	26
FATIGUE	NO	14	13	27
		19	34	

In crosstabulation analysis, the hypothesis that variable Y is independent of variable X is frequently tested. This is done by computing the cell frequencies that would be expected if no relationship is present between the two variables given the existing row and column totals displayed in the crosstabulation. The expected cell frequencies are then compared to the actual values found in the table by using the χ^2 test of independence. In the case of crosstabulation, the χ^2 statistic is:

$$\chi^2 = \sum_i \frac{(f_o{}^i - f_e{}^i)^2}{f_e{}^i},$$

where

$f_o{}^i$ = observed frequency in each cell

and; $f_e{}^i$ = expected frequency in each cell.

For a given number of observations, the higher the value of the calculated χ^2 statistic, the more likely that Y is, in fact, dependent upon X. By comparing the calculated χ^2 statistic with a table of percentiles of the χ^2 distribution, the acceptance or rejection of the hypothesis that Y and X are independent can be made at a certain level of significance (e.g., 95 percent).

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